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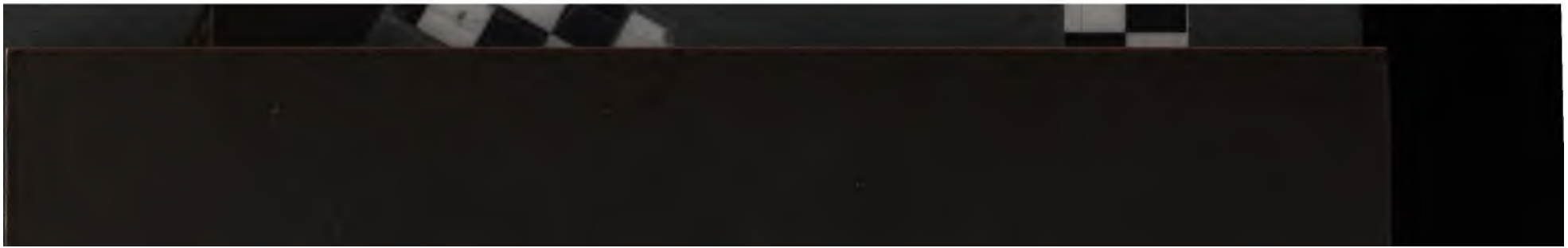

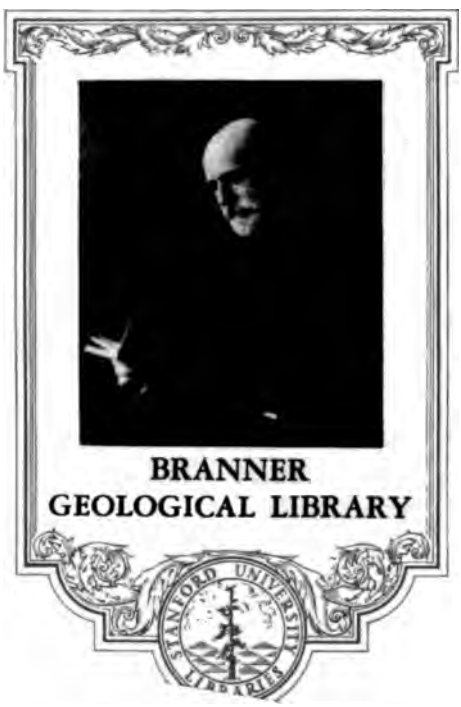
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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 5

IRRIGATION PRACTICE ON THE GREAT PLAINS.—COWGILL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 125 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 393 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1891, also the assessment of the Director of the survey to the House Committee on Irrigation, and other papers including a bibliography of irrigation literature. Illustrated by 20 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1893, octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains a report upon the location and survey of reservoir sites during the fiscal year ending June 30, 1893, by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 48 plates and 109 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell, quarto.

No. 25, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 86, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 123, Irrigation in Montana; No. 137, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 179, Irrigation in Oregon; No. 190, Artesian wells for irrigation; No. 195, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 53, September 9, 1892, quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the several regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891–92, Part III, Irrigation, 1893, octavo, 466 pp.

Consists of three papers: Water supply for irrigation, by F. H. Newell; American engineering and contingent results of the Irrigation Survey, by Herbert M. Wilson; Construction of topographic maps and execution and survey of reservoir sites, by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893, octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic formation in and adjacent to the Cascade Mountains between Yakima River and the great plateau of the Columbia in the west of this area, with special reference to the conservation of artesian waters.

(Continued on third page of cover.)

J C Branner

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 5

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

IRRIGATION PRACTICE ON THE GREAT PLAINS

BY

ELIAS BRANSON COWGILL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, March 3, 1897.

SIR: I have the honor to transmit herewith a paper entitled "Irrigation Practice on the Great Plains," by Prof. E. B. Cowgill, and to recommend that it be published in the series of papers upon water supply and irrigation. Professor Cowgill's experience as a practical farmer and irrigator and as the editor of an agricultural paper renders his observations upon irrigation practice of especial value in discussions of the methods of utilizing the water resources of semiarid areas.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

IRRIGATION PRACTICE ON THE GREAT PLAINS.

By E. B. Cowgill.

GENERAL STATEMENT.

The characteristics of topography and climate which influence the practice of irrigation on the Great Plains may be summed up in the general statement that the land is usually smooth, the soil extremely deep and fertile, the rainfall scanty and irregular, the sunshine abundant, and the water supply variable and uncertain. In seasons of unusual rainfall a stranger entering western Kansas is astonished that a land of such remarkable productiveness has been almost abandoned since its first settlement. Coming again after a season of deficient rainfall he would be equally surprised that anyone could have been tempted to try to make a living on the barren prairies. Happening upon a spot where irrigation is practiced, he at once appreciates the enormous importance that water bears to the successful settlement of the country, for there agriculture on a small scale is profitable no matter what may be the character of the season; there all of the elements—soil, sunshine, and water—combine to produce a fruitful increase of plant life.

The water supply of the region, at best scanty, is yet ample for the development of considerable areas, far greater than are at present occupied. In this paper it is not proposed to discuss what or where these sources are, but, assuming that water is to be had from surface streams, storm waters, or wells or other underground sources, the attempt is made to describe in a general way to the farmers, especially to those who have not practiced irrigation, the methods of controlling, storing, distributing, and applying the waters to the cultivated fields. It is recognized that no description can ever take the place of actual experience, but it is possible to give general directions which the individual farmer, by experiment and observation, can adapt to his peculiar needs.

RESERVOIRS FOR STORM WATERS.

Artificial reservoirs have been found a necessity in the irrigation of the plains. Storm waters can not be controlled or directed upon the land as they fall. They run off from the hard, sun-baked prairies in torrents, especially in those portions of the country where reliance must be placed chiefly on such waters. For the storage of this water reservoir sites are easily found, and are usually selected with a view to impounding the water from a considerable drainage area. The retaining dams are of various sizes, according to the needs and the means of the persons constructing them. A reservoir to contain an acre or so of water is easily made by placing an earthen dam across the outlet of the drainage area, even though the slopes may be very gradual. The dam has not usually to be built very high, and the principal precaution necessary is to provide against washing out in time of freshet. The larger reservoirs differ in no essential from the smaller, except that the sites must be selected with reference to larger areas of drainage, and the dams usually require more work, both as to engineering and construction.

A typical example of this kind is the reservoir of George M. Munger, of Greenwood County, Kansas. Mr. Munger is engaged extensively in orcharding, having 500 acres of fruit trees ready to bear. Notwithstanding his location near the ninety-sixth meridian, far within what is usually designated as the "rain belt," he has concluded, after careful investigation of the subject, that the realization of the expected profits of his orchard is dependent to a large extent upon the artificial application of water. There are no surface streams near from which to obtain water in the usual way. There is on his farm, however, an eligible site for a storm-water reservoir. But most of his orchard and farming land is at a higher level than the reservoir site, so that, after collecting the water, he is obliged to pump it.

The accompanying view, Pl. I, gives the relative location of the orchard and source of water supply. The storm reservoir can be seen in the distance to the left, while between it and the orchard is the pumping station. The ravine in which the dam is placed runs diagonally through the farm. The sides of it have a gentle slope, thus necessitating the construction of a dam of considerable length, as shown in the illustration, Pl. II. In order to provide a safe and sufficient spillway, it was necessary to build the dam to considerably larger dimensions than would otherwise have been essential. The topography is such that water could be wasted over a natural ridge having a breadth of about 1,000 feet. It was therefore decided to carry the dam to a sufficient height above this ridge to hold in check any freshet of unusual size and turn it over the crest of this depression.

The watershed above the point at which the dam is located is about 800 acres in extent. The valley shows by watermarks that the high

MUNGER ORCHARD, GREENWOOD COUNTY, KANSAS.

MUNGER RESERVOIR DAM.

floods spread out to the width of about 300 feet. The dam is 2,582 feet long, 192 feet broad at the widest part of the base, and a little less than 40 feet at the highest point above the bottom of the valley. The estimated area of water when full is 160 acres, and the estimated capacity 1,600 acre-feet.[1] It was expected that two years of average run-off would fill the reservoir.

In the construction of the dam, which was built exclusively of earth, the sod was entirely removed and placed at the rear face. The old water channel was thoroughly cleansed of the washed-in gravel, and the work begun with new earth. The soil is a heavy clay with the usual variations, including probably a full supply of gumbo and alkali.

The matter of seepage through the dam and the method of correcting it was considered by Mr. Munger, who states in general terms that while the authorities on the construction of earthen dams recommend that the earth be especially selected for the face, and a puddle trench be placed in the heart of the work, it seemed difficult to formulate a scheme for so doing that did not involve too great expense. Earth was taken as it came in the borrow pits, and in each successive pit was used as deep as it could readily be obtained. All earth was taken from inside the work, except where it could not be had without too great a haul. Several smaller dams had been previously constructed on the place, and in each and every place there was a seepage along the toe of the dam, but in no case was it sufficient to endanger the stability of the work. The same trouble developed in this work, and on account of the magnitude of the dam it was deemed expedient to correct it. This was accomplished by running a permanent stone drain along the toe of the dam, grading it to the lowest point possible, and running laterals to every seepy spot that showed. The result was very satisfactory, there having been a small stream running from the drain constantly since its construction, but now materially reduced in volume.

The original estimate shows about 100,000 cubic yards as the earth contents of the dam, but, on account of the action of the waves on the surface of the dam, it was found that the estimate was considerably exceeded. It was found impracticable to prevent, by riprapping, the water from bringing the face of the dam to the natural grade, so that no protection had been provided against the action of the waves until the grade determined by the water was made, when the face of the dam was riprapped to prevent further loss of earth from the action of the waves.

Except for the fact that Mr. Munger has many hundreds of acres of land to irrigate, so large a construction would not be advisable, but the plan of this reservoir and the methods pursued in its construction

[1] Irrigating a 500-acre orchard, by George M. Munger: Report of the Kansas State Board of Agriculture for the quarter ending March 31, 1895, pp. 66–71.

may well be taken as models by those whose requirements demand reservoirs of only moderate size. Water may be drawn through a flume for the irrigation of considerable areas of Mr. Munger's farm which lie at a lower level than that of the water in the reservoir, but for most of the farm it is necessary to raise water. This is done by two compound, duplex, direct-acting steam pumps of a daily capacity of about 4,000,000 gallons, which forward the water rapidly enough to make unnecessary a distributing reservoir from which to draw the water when supplying it to the land.

RESERVOIRS FOR PUMPED WATER.

Reservoirs for pumped water differ in several respects from those for storm water. The site for a pumped-water reservoir should be selected on the highest part of the land to be irrigated. The form will not usually be determined by the contour of the land, but by the taste or convenience of the irrigator. Not infrequently such reservoirs are made square, or at least rectangular. Some are made circular, thus securing the greatest content for a given amount of embankment. In size, pumped-water reservoirs vary from quite small, as shown by Pl. III—say 30 feet square—to those containing half an acre or an acre of ground. Irrigation with pumped water has been confined to small operations, at least in Kansas and upon the Great Plains, making large storage capacity unnecessary. Since pumping into the reservoir is done almost exclusively with windmills, the work of which varies with the wind, it is sometimes thought that the size of reservoir, compared with the land irrigated, should be considerably increased above the dimensions now in common use. But the practice has been to use the reservoir as an accumulator, giving the irrigator command of his water supply rapidly, rather than as a store against the time when water may not be obtained by the aid of the wind. Experience has confirmed the practice of using the reservoir merely as an accumulator, except for large gardening operations, for which a delay in the application of water sometimes proves disastrous. With other crops it is found quite possible to anticipate probable scarcity by storing abundance of moisture in the porous subsoil. The relative size of the reservoir to the land to be irrigated averages from about 1 to 80 to about 1 to 100.

The depth of the reservoir when first constructed is generally 4 feet; that is, the bank which constitutes the dam all around the area to be filled with water is raised about 4 feet above the natural surface of the soil, as shown in fig. 1. The earth for the construction of the dam is usually taken from within the reservoir, so that the depth of water in the reservoir would be somewhat more than 4 feet if it were filled to the top of the bank.

SMALL IRRIGATION RESERVOIR, AT GARDEN, KANSAS.

Reservoirs are, as a rule, made on land which has been under cultivation. In preparing for the work all trash should be removed and the ground which is to serve as the foundation of the dam should be about four times as broad as the height of the proposed embankment around the reservoir. It is a good plan in plowing this foundation to turn the furrows so as to leave a dead furrow in the middle and then to pump water into this dead furrow, wetting all the base of the dam

FIG. 1.—Reservoir and windmill north of Garden, Kansas.

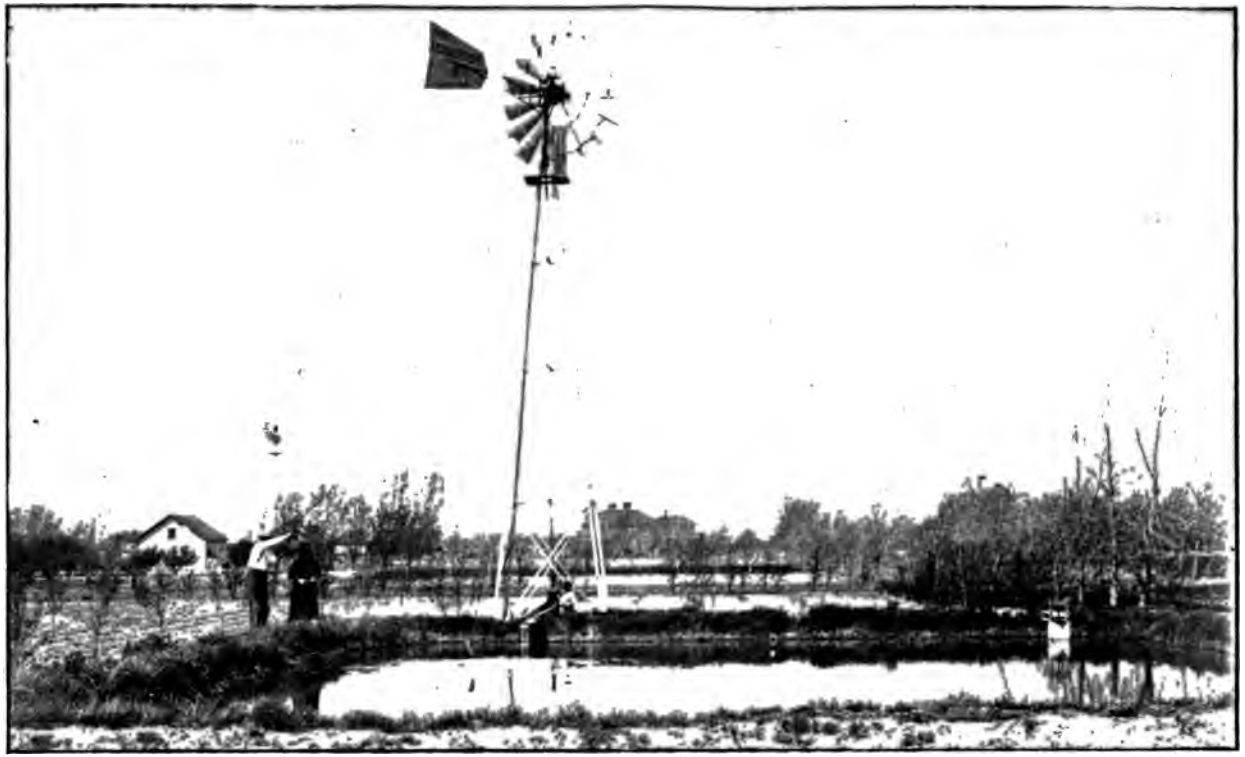
thoroughly. After this has sufficiently settled to admit of driving over it, it is well to tramp it by driving horses or other heavy animals over it until it is well compacted. The land in the interior of the reservoir is plowed and the loose earth is removed to the embankment, usually with the ordinary slip scraper, although in the construction of very large reservoirs wheeled scrapers are sometimes used.

In depositing the soil which is to constitute the embankment, it is

better to keep the parts which will become the faces higher than the center, thus leaving a channel all around through the whole of the embankment. At the close of each day's work care should be taken that this channel be continuous, and that the top of the embankment be about the same height all around, so that water may be pumped into the channel in the heart of the bank, thoroughly soaking it. In soils at all likely to seep it is very important that the precaution of soaking the bank daily as it is built be observed. If not made too soft in the evening, it will usually be in condition to tramp in the morning, and this should be done by driving repeatedly around on top of the embankment made. If each day's work is treated in this way, there will be little trouble from seepage through the bank of the completed reservoir.

The crumbling soils of Kansas will usually take about the correct form for a bank as deposited from the scraper and under the tramping here recommended. Some who prefer to have the banks steeper than they are usually left in this way trim them up with a shovel, afterwards sodding to prevent further crumbling. This answers very well for the outside of the dam, and sod used inside, as shown in fig. 1, is a protection against washing until the soil shall have become so thoroughly settled as to be less affected by the action of the waves. If the reservoir be small, it is sometimes inexpedient to take from the interior the entire amount of earth required for the embankment. Experience has shown that soil near the surface more readily becomes a water holder than does that from the substratum. In any case it is not safe to employ the gravelly subsoil which prevails almost everywhere in the larger valleys of western Kansas.

After the completion of the bank, the next work is to make the bottom of the reservoir water-tight. This is done by plowing the entire area to a depth of 3 or 4 inches, harrowing it fine, and then pumping in enough water to cover the entire bottom—if, indeed, it does not seep out too fast to admit of this. In any case, water should be pumped in until a considerable area is thoroughly soaked. As soon as this is settled sufficiently, so that heavy animals will not sink in more than 6 or 8 inches, horses or cattle are turned in and driven around over the water-soaked area until it becomes hard. Then more water is pumped in and a larger area soaked. It is usually found that after the first partial soaking and the subsequent tramping the entire area of the bottom may be covered with water. Enough water should be put in to thoroughly soak every foot of the area, so that it would be dangerous to immediately take large animals into it. After a few days, however, this will have settled so that animals may be safely driven over it, when it should be tramped continuously until it becomes so hard that the hoofs of the animals scarcely mark it. Such puddling rarely fails—even in very open soils and in those which seem to be nearly all sand—to make a reservoir so tight that the



SMALL RESERVOIR, SHOWING WINDMILL AND OUTLET, AT GARDEN, KANSAS.

ge under 4 feet of water is insignificant. In rare cases it may be sary to throw in manure, or at least straw or hay, and again and tramp, but generally there is enough organic r in the surface soil to puddle sufficiently with- he addition of any other material. Some prep- ons have been advertised as linings for reservoirs, he cheapest and undoubtedly the best lining is as puddling as can be done with heavy animals.

ery reservoir must, of course, be provided with a ble outlet for the water, and unless careful atten- o the pumping can be relied upon there should so an overflow or waste-way. The outlet flume d be provided when the reservoir is laid out and e the banks are completed. The bottom of the t should be placed as low as the bottom of the outside, as shown in fig. 2, but is usually not so s the bottom of the reservoir inside, so that the r is not all drawn from the reservoir. It is found reservoirs retain their ability to resist seepage r if never entirely drained. This is especially in the winter season, when, if allowed to freeze, uddling of the bottom frequently becomes so de- ated as to necessitate renewal. The flume should ng enough to reach entirely through the embank- . It is usually made of 2-inch planks, with a opening of 6 by 8 inches. Where large areas are irrigated, making rapidity of supply essential, ox should be made larger, and for field work an ing of 12 by 16 inches will be found ample. It is lways necessary to use the full size of the open- but the flow is regulated by the extent to which alve or gate is raised.

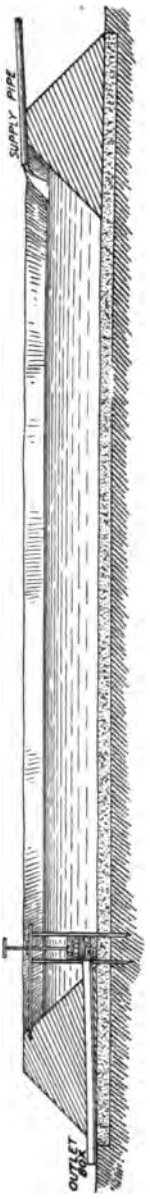


FIG. 2.—Diagram of reservoir and outlet.

veral forms of valve have been used. An excel- one is shown in the illustration, fig. 3, from a as experiment station bulletin.[1] This gives a per- ive view of the outlet box with guides attached olding the valve or gate. This is faced with leather ely held by tacks. The gate is best operated by penter's bench-screw attached to a suitable sup- and engaging a nut on the upright standard. fficient gate is also shown in the illustration, Pl. perated by a lever and rod extending through the t box. Whatever form of flume is used, it is bet- o have one or two bands of cleats around it, taking care that

[1] ll fruits by irrigation: Experiment station, Kansas Agricultural College, Bulletin No. 55, ber, 1895, p. 134.

they fit water-tight to the planks. In placing the flume it should be very thoroughly embedded in the bank, care being taken to ram the earth firmly against the planks, especially on the under side, in order to prevent the water from creeping along between the planks and the earth. The extra work in properly bedding the flume is worth many times its cost in security against leaks.

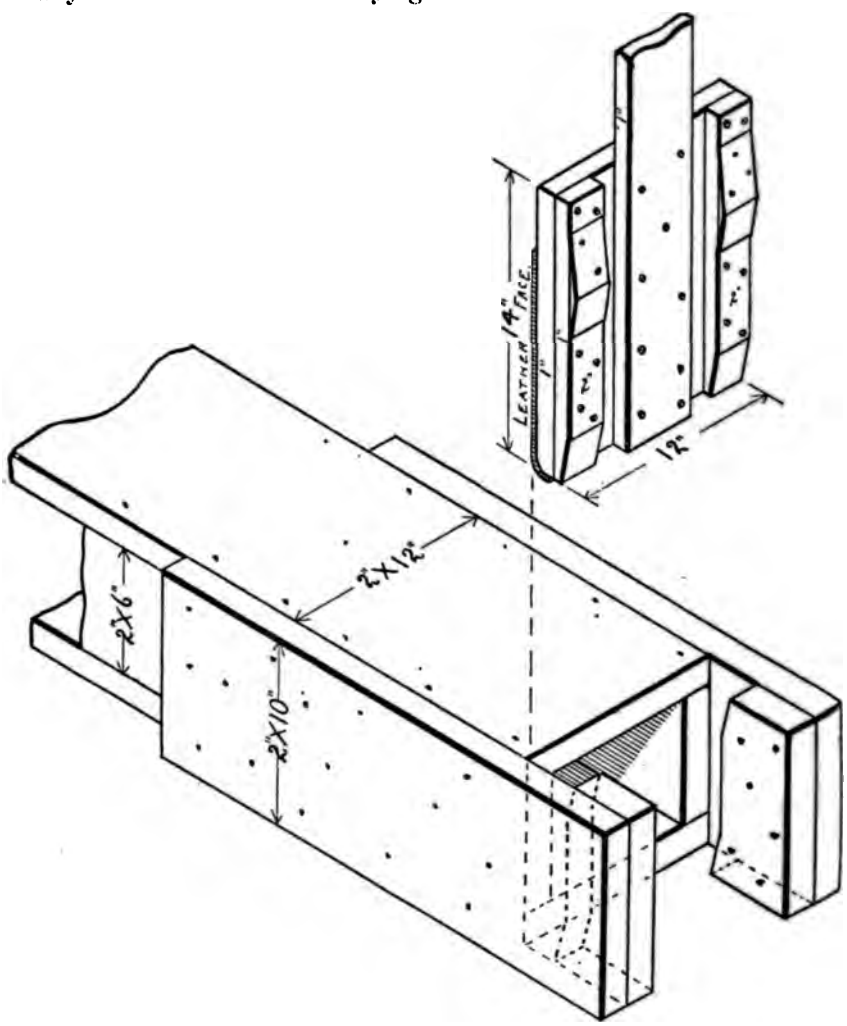


FIG. 3.—Reservoir flume and gate.

Little expense is needed to prepare an irrigation reservoir for the abode of edible fishes. It is requisite, however, to place wire screening in front of the gate, so that when water is to be drawn from the pond no fish can pass through the flume. A light framework is usually constructed, of such dimensions as to allow the gate to be opened *without* interfering with it, and this is covered with common wire netting, *of the sort* used for fly screens. This rusts out somewhat readily,

RESERVOIR AND IRRIGATED FIELD, AT GARDEN, KANSAS.

but is cheap and easily renewed. Screens of brass wire, while costing more at the outset, last much longer. The water as pumped from the wells into the reservoir is perfectly clear, and is usually at a temperature of about 58° F. This is not ideal water for the abode of carp; nevertheless, this variety has been more cultivated than any other, largely on account of its prolific increase. The growth of the carp is, however, somewhat disappointing, and this is probably due to the fact that, owing to the continual additions of the cold well water from the pump, the temperature of the water is below that at which the fish thrives best. Channel cat, crappie, and black bass have been found to do well. Some attempts have been made to grow trout in these ponds, but without success.

If irrigation reservoirs are not otherwise used in the winter, they form excellent ice ponds, and make available what would otherwise be an expensive luxury. But if water is continually pumped into the pond, especially in the more southern portions of the district, ice is but scantily formed. It is possible, however, for a farmer who has a reservoir to provide himself with a sufficient supply for the dairy and other purposes, even though he use his reservoir for irrigation during much of the winter.

DITCHES.

Not every tract of land has such conformation as renders irrigation practicable. Land the surface of which is formed into mounds of considerable magnitude may well be discarded, at least until that of more even contour shall have been brought under irrigation. Ridges and terraces are not especially objectionable features. It scarcely seems necessary to remark that irrigation is practicable only where water can be induced to flow over the land, and that water will not flow uphill, although the eye is often deceived and the novice at his first observation of the use of water through irrigation ditches receives the impression that in some parts of the work water is actually flowing up grade. And the most practiced are sometimes, indeed frequently, mistaken as to whether the surface of the land rises or falls in a given direction. It is therefore important, in the location of ditches, that a preliminary survey of the land be made; and it is a good plan to make a contour map of the land to be irrigated before locating the ditches. In irrigating from reservoirs it is essential, as before stated, that the reservoir be placed on the highest part of the land to be irrigated.

Ditches, as well as reservoirs, should be kept on land at least as high as, and generally a little higher than, that to which they are to supply the water. One of the largest and most successful irrigators of farm crops on the plains, C. D. Perry, of Englewood, Kansas, holds that in laying off the ditches it is necessary to forget all about directions of land lines and points of the compass, and be governed entirely by the contour of the *surface to* be irrigated (see Pl. VI).

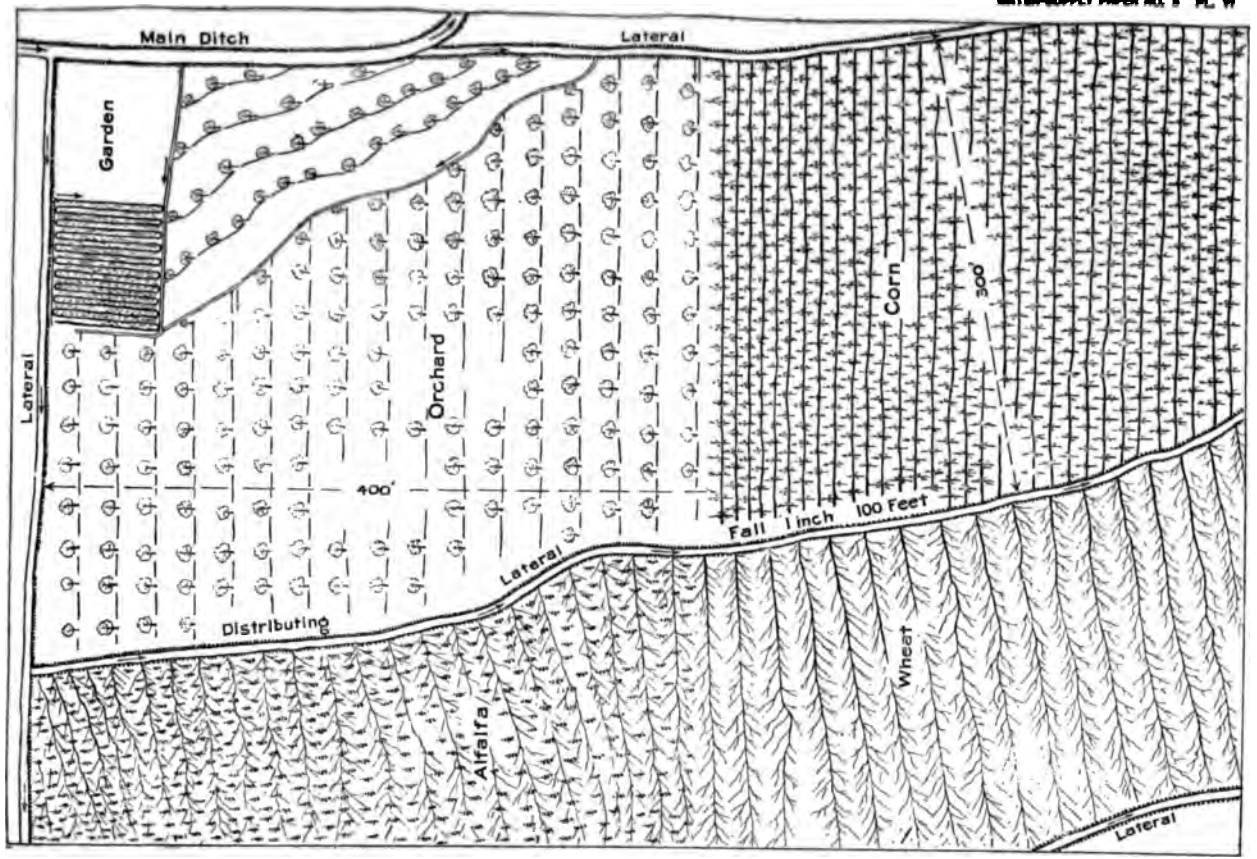
It is easily believed that the ditches must be carried along at a proper grade, and that the water can not be made to pass a hill by flowing up it, but only by following a course which gives a continuous though slight fall; but on the smooth surface of the plains, constituting not only the river bottoms but also the plateaus of the region, the unaided eye sees no reason why the water may not flow in one direction as well as another, or why it may not be made to follow the direction of the land lines without serious inconvenience. In some cases this can be done, but in others it is entirely impracticable.

These distributing ditches, or laterals, should be placed at such distances apart that the water may flow over the land from any ditch to the one next lower down the slope in so short a time that there will be no great difference between the amount of water taken up by the portions of the land on the different sides of the tract. This distance varies somewhat in different soils and on different slopes. Some have placed their ditches as far as 80 rods (1,320 feet) apart. Usually it will be found better to have the ditches not more than one-third this distance apart, and not infrequently it is better that the interval separating them be not more than 20 or even 16 rods.

Water flows when the fall is very slight. In large ditches, free from short bends, a fall of 12 inches per mile produces a good current, while in such ditches a fall of 30 inches per mile often produces such a current as to cut the banks. For small ditches, such as are used for distributing from pumped-water reservoirs, a considerably greater fall is admissible and even desirable, and for laterals from which the water is made to flow over the land a fall of 1 inch per 100 feet is the correct standard. Where it is possible, they should be laid with such courses as will give them this fall.

In size irrigating ditches vary greatly. In some cases the lister furrow, with the loose earth removed, is large enough, while for the conveyance of water for large areas canals several feet wide and carrying water 2 or 3 feet deep are sometimes used. When Mr. Perry was irrigating but 1,200 acres of land with water from the Cimarron River, his main ditch was 16 feet wide at the bottom and carried water about 2 feet deep, and its sides sloped about 2 to 1. As his irrigating operations were increased beyond this amount, he enlarged the ditch in order to have command of a larger supply. But irrigation from a pumped-water reservoir is usually confined to a single farm, varying from 1 to, say, 40 acres in extent. For the 40-acre farm a ditch as shown in Pl. VII, 5 feet wide at the bottom and carrying water 15 inches deep, with sides sloping 2 to 1, will probably be found as large as needed. The laterals leading from this main ditch over the land to be irrigated will generally be much smaller than this perhaps not more than half as large, or even less, according to the amount of land to be served from them.

In the construction of ditches the implements used are the plow



PLAN OF PERRY FARM, CLARK COUNTY, KANSAS.

DISTRIBUTING DITCH.

and some sort of appliance for removing the loose earth from the ditch. The line of the ditch having been determined, furrows are plowed, throwing the soil from the middle to either side, and the size of the ditch controls the distance between the furrows of the first round. Very many ditches are made by plowing this first round in such a way as to leave the width of one furrow of a 14-inch plow in the middle. This is then turned out toward one side, and another furrow is turned from the bottom of this last furrow toward the other side of the ditch. It now remains only to remove the loose earth from the bottom of the ditch to the top of the banks. This operation is most rapidly performed by an instrument called an "A," from its resemblance in shape to that letter. It is constructed of planks, usually shod with steel or iron along the lower edges. After being suitably weighted it is drawn by means of horses, apex first, through the ditch. By suitably placing the weight, one side of the A, usually designated the land side, is made to follow along near the middle of the bottom of the ditch, while the other side throws about half of the loose earth out upon one bank. The return trip throws the other half of the loose earth out on the other bank, and, with the exception of a little finishing with the shovel, completes the ditch.

Larger ditches require more furrows and further use of the A, but are constructed in essentially the same manner. So also, in a ditch which at any place is to be made deeper than the average, a little extra work is done with these implements in that particular part. It is important in the construction of ditches that the banks be made tolerably uniform in height, and be so constructed as to carry water somewhat above the ordinary level of the land. For the distributing laterals banks 6 inches above the general level of the land to be irrigated are about right; if they are made a little higher, so as to be 6 inches after settling, so much the better. For rapid irrigation the ditches should be at all times capable of holding water to at least 4 inches above the level of the field.

DISTRIBUTING WATER.

In irrigating it is necessary to have water spread with as much uniformity as possible to all parts of the land. Fields which appear to the casual observer to be entirely without features of undulation are often found, when inspected with a view to irrigation, to possess elevations and depressions not suspected before. The practical irrigator finds that an elevation no greater than the thickness of a man's hand may turn the water entirely around a portion of his ground. So, also, a very slight depression is always found by the water, and is liable to be overirrigated, water-logged, and thereby caused to settle, increasing the disparity of the surface. It is therefore necessary that almost every piece of ground which is to be irrigated should be graded.

Grading may be done either before or after the construction of the

ditches. It will usually be found that if the ditches are made first, or at least located, less grading will be required than would be considered necessary before the location of the ditches. There are various grading machines, all of which are operated by horsepower, and some of which are very simple. Some excellent graders are on the market at reasonable prices, but many farmers construct their own of planks, and with them do quite as good work as could be done with any machine built. Usually a few turns with the grader suffice to fill up a low place, and often at the same time to remove an elevation. It should be remembered that grading is of the nature of a permanent improvement. Once thoroughly done, it has never to be done again.

Water is thrown out of the ditches by means of dams, the use of which will be described presently. The most convenient form is the canvas dam. The materials used in the construction of a canvas dam are a piece of timber, usually a 2-by-4 scantling, long enough to reach across the top of the ditch from bank to bank; a small stick varying in length according to the width of the ditch to be dammed, but no longer than will lie across the bottom of the ditch without leaving any considerable space between the stick and the bottom; a brace or stick about one-third longer than the depth of the ditch, and a piece of canvas about one-third wider than the depth of the ditch and as long as the width of the ditch at the upper edge. The canvas is cut into a trapezoidal shape, somewhat resembling but larger than a section of the ditch. The long edge of the canvas is fastened to the scantling first described and the short edge to the small stick. It is well to have a little margin of the canvas below this short stick. The dam is placed by throwing the scantling across the ditch just below the point at which it is desired to divert the water, as shown in the illustration, Pl. IX. The canvas rests in the ditch, with the short stick lying across the bottom, far enough upstream from the location of the scantling to make the canvas nearly tight. The brace is placed with one end against the scantling and the other against the short stick, thus preventing the canvas from being washed back under the scantling. A little earth is thrown upon the loose edges of the canvas where it rests against the banks and against the bottom of the ditch, and the water is turned in. The weight of the water presses the canvas closely against the banks, so that there is scarcely any leakage. In some cases permanent dams with head gates are placed in the ditches, and this is more often done where ditches branch and it is desirable to divert the water to the one or the other branch.

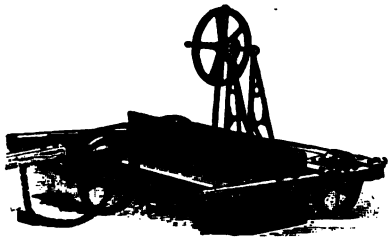
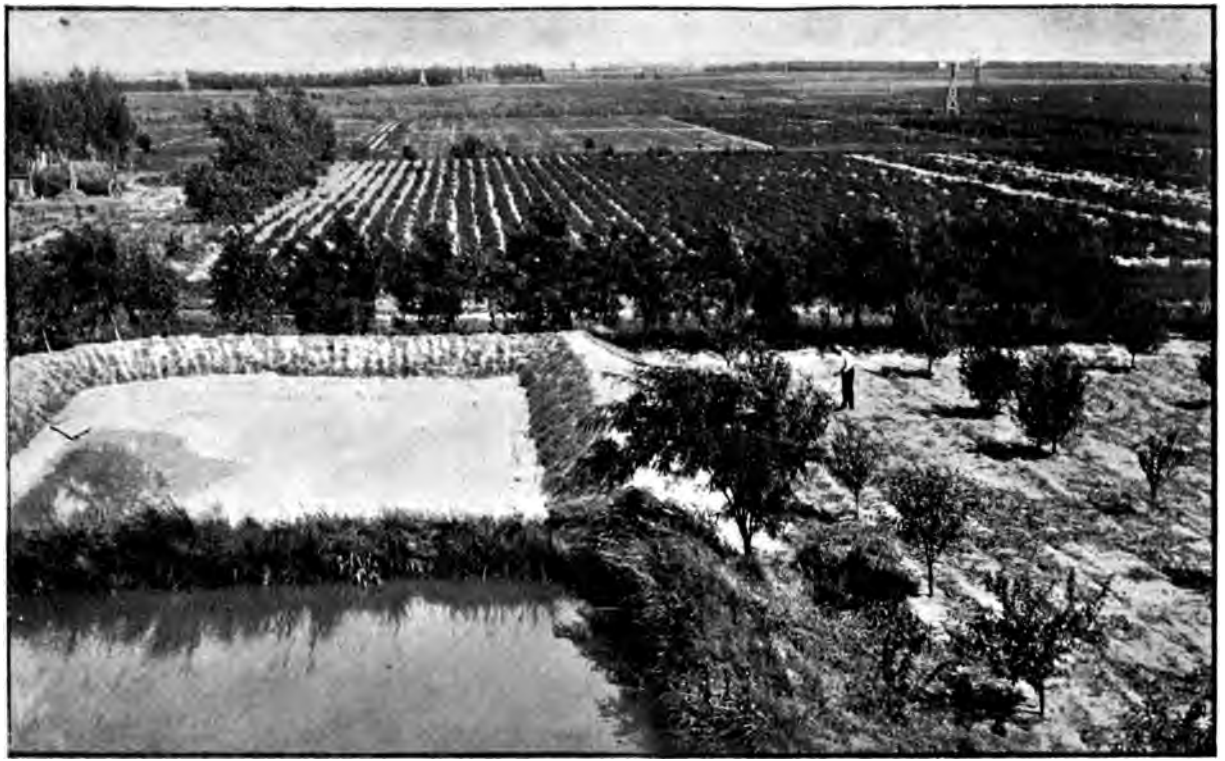


FIG. 4.—Land grader.



RESERVOIR AND GARDEN, AT GARDEN, KANSAS.

CANVAS DAM IN DISTRIBUTING DITCH.

A more primitive dam is sometimes made of earth, and such a dam is quite effectual and easily made in very small ditches. Sometimes a board is cut into the banks, and earth thrown in above it, making an effectual dam for ditches of considerable size; but for general purposes, where it is not worth while to put in permanent dams with flumes, canvas dams are most effective, and are placed and removed with less labor than any other. It is well that the irrigator be provided with at least two canvas dams suitable for each size of ditch from which he wishes to divert water.

METHODS OF WATERING.

That which has gone before is preliminary to the final object of applying water to the land at such times as the interest of the farmer or gardener suggests. There are two principal methods of watering, and a third is especially attractive to the novice and the amateur, and is not without its uses in some cases. For sowed grains, meadows, and pastures water is supplied to the land by flooding; that is, by allowing it to flow as completely as possible over the entire surface, but only in such volume as will not cause washing. For crops planted in rows and for orchards irrigation by furrows is generally preferred. The third method is by underground pipes, into which the water is passed, to be distributed through the soil by capillary attraction or surface tension, rising from below to near the surface, rather than passing from the surface downward, as in the other two methods.

Irrigation by flooding presupposes that the work of grading has been thoroughly done and that the ditches have been laid out and constructed with care. Take, for example, a meadow which has been thus prepared. The irrigator proceeds to a point in one of the laterals leading through this meadow 400 feet down the lateral from the point at which it enters the meadow. Here he places his canvas dam in the lateral, then admits the water. It will be remembered that the banks of these laterals are constructed so as to be 6 inches higher than the surface of the adjacent field. As soon as the water has risen 4 inches above the level of the field at the dam, or within 2 inches of the top of the bank, the irrigator makes a small opening in the bank just above the dam to the level of the water. At a distance of a rod or so farther upstream he makes another small opening, and so on throughout the 400 feet to the edge of the meadow. By this time the water is pouring out through all of these openings, giving a small stream at each. These streams spread over the ground and very soon widen into a broad sheet, which, with much irregularity of front, spreads downward toward the next lateral. If the grading has been well done, so as to give a uniform surface to the meadow, there should be no dry spots left after such an irrigation. If the grading has not been perfectly done and the water has inclined to flow around certains areas,

it is necessary for the irrigator to take his shovel and, beginning at the point where the water begins to flow around, open a shallow channel through the highest part of the dry area, thus leading the water from the upper side and securing practically uniform irrigation. The water is allowed to continue running until this section of the meadow has been thoroughly moistened to such depth as the irrigator desires. With fresh ditches it is necessary to watch carefully that none of the openings in the bank becomes seriously washed and gets too large. When such trouble begins it is quite easily remedied by throwing in a shovelful or two of soil. When the ditches have become well settled, little trouble in this respect is experienced.

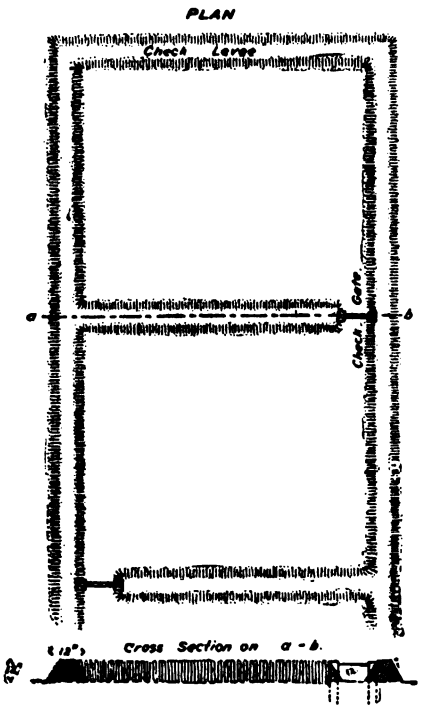


FIG. 5.—Diagram illustrating flooding in rectangular block.

While the water is flowing over this first section of the meadow the irrigator places a second canvas dam at a point about 400 feet farther down the lateral than that at which the first was placed. When the irrigation of the first section is completed, the dam first placed is removed and the water is allowed to flow down the lateral to the second dam. Openings are made in the ditch as before and the second section is irrigated in manner precisely like the first. The dams are thus removed to positions successively 400 feet farther downstream, and sections of this length are thus irrigated. The same course is pursued with each of the other laterals until the entire meadow is gone over.

It will be remembered that in speaking of ditches the proper fall was stated to be 1 inch to 100 feet. By making the opening nearest the dam so that its bottom is 4 inches above the level of the field, the water will rise to that height, and the bottom of the last opening, 400 feet farther up, will be just at the field level. If for any reason it has been necessary to give the ditch a greater fall than 1 inch to 100 feet, the dam is placed at correspondingly shorter intervals, unless the banks of the lateral have been made so high as to carry water more than 4 inches above the level of the field. For subsequent irrigations, if the ditches have not been disturbed, the dams may be placed in the same positions as at the first irrigation, and no new openings in the bank will be necessary,

EARTH DAM IN DISTRIBUTING DITCH.

the old openings being as available as at first, for on the removal of any dam the water immediately falls, so as to cease flowing through the openings above, the entire fall being 4 inches to the level of the openings of the next lower section. It is never necessary to close the openings when once properly made, and the only attention needed is to prevent or repair washes and to maintain all parts of the bank at sufficient height to prevent overflows other than at the points desired. Where an abundant head of water is available and old and well-settled ditches are used, it is often possible for the irrigator to attend to the dams and openings in more than one lateral, thus increasing the rapidity of the work. This method is applicable not only to meadows and such sowed crops as wheat, oats, rye, barley, etc., but it is sometimes used for corn or orchards, and indeed for almost everything except potatoes.

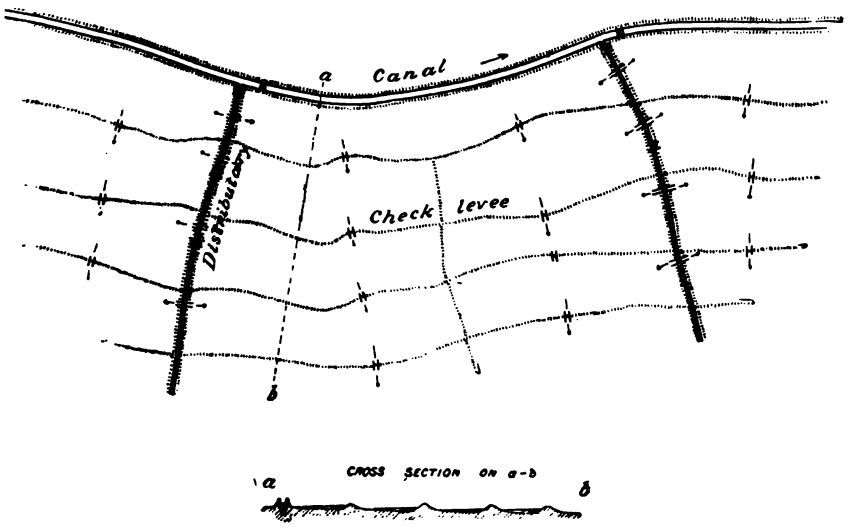


FIG. 6.—Diagram illustrating flooding within levees on irregular ground.

A modification of this system is used for some garden crops. Thus celery requires frequent and copious irrigation. The ground on which it is planted may be made into perfectly level beds, each having a border a few inches high completely inclosing it. The celery is irrigated by allowing sufficient water to run into this inclosure to cover the ground and settle into it until it is sufficiently moistened. Some celery growers irrigate in this way every two or three days from the time of planting until just before the celery is gathered.

This bed system is sometimes applied to field work. The borders are made somewhat higher, and the beds are made to contain in some cases several acres each, according to the head of water available and the configuration of the surface. In field work the borders are made on contour lines, and are thrown up with the plow, and so rounded

over the surface as to admit of mowing or cultivating over these elevations, so that the area of the embankments is neither wasted nor left to grow up in weeds.

This bed system, while at one time received with much favor for field work, is gradually giving way to the flooding system, as previously described, and to the furrow system, to follow.

In preparing for irrigation by the furrow system, the distributing laterals are made in all respects as described for the flooding system except that it is practicable to have them somewhat farther apart. The rows of crops, as corn or potatoes, are made to terminate at the laterals from which they are to be irrigated, but it is not essential that they meet these laterals at right angles. When the water is to be applied, small furrows are made down the rows, care being taken that the loose earth does not roll back into the furrows so much as to obstruct them at any point. These furrows extend from one distributing lateral to the next. Canvas dams are used as in flooding. The openings in the laterals are made at suitable intervals, and the water from each of these openings is turned into four or five furrows and allowed to trickle slowly down the furrows to the next lateral, and to continue flowing until the entire section is thoroughly irrigated.

The size of the streams needs careful and intelligent attention. If the water be allowed to rush down the furrows so rapidly as to become turbid by picking up the finer particles of soil, these particles will be deposited farther down the furrows as the volume of the stream becomes smaller and the current becomes less on account of the absorption of a part of the water in the soil traversed. This deposit of fine particles is apt to act as a cement to the furrows and prevent proper absorption of the water. It is possible by the very rapid use of water to cause it to flow through the entire length of the furrows without effectually irrigating the soil. The novice at irrigation is almost sure to be surprised at the action of an irrigating stream in the furrows in a soft, plowed field. If the stream is very small, it may entirely disappear in the first rod or two of the furrow. If the stream is very large, it may carry away a considerable part of the soil from the first few feet or few rods of the furrow, and, as already stated, flow through without accomplishing the purpose of effectually moistening the land.

A properly regulated stream should flow through a furrow without becoming very turbid at any point, and should progress continuously, though slowly, throughout the length of the furrow. After it has flowed for a time, varying with the nature of the soil from a few to many hours, the land should be so thoroughly irrigated as to make it, especially if newly plowed, too soft to walk over without miring. Where the soil is of a flocculent structure and contains considerable vegetable material, this thorough irrigation may take place by the

FURROW IRRIGATION.

furrow system without greatly changing the loose and flocculent structure so desirable for rapid growth of vegetation. This is the acme of irrigation. Not every soil will retain this open structure, even under the most skillful handling of water. With many soils it is found that the effect of the artificial application of water is much like that of an exceedingly heavy and dashing rain, solidifying the soil by breaking down the open structure. It may be said that, as generally applied, irrigation leaves the soil compact and in condition to become very hard as it dries.

CULTIVATION.

The compacting of the soil after irrigation is remedied by cultivation of the surface as soon as the soil reaches a condition to be worked. This cultivation after irrigation serves the double purpose of checking the growth of weeds, which is sure to be copious, and of leaving a soil mulch of loose earth over the surface, which prevents the rapid evaporation of the moisture stored in the subsoil. The importance of cultivation after each irrigation can not be overestimated. In general the application of water without the subsequent cultivation is of little value, and, indeed, in many cases it is absolutely detrimental. The general experience is that, with the average soil, after the application of water the ground soon becomes very dry and very hard, and evaporation proceeds to rob both the soil and the subsoil of moisture with surprising rapidity. If the irrigator thinks to remedy the case by another irrigation, he usually only makes the matter worse, for the soil by this time, especially that along the borders of the furrows, has become quite thoroughly puddled, so that the second application of water with no intervening cultivation amounts to little more than flooding over the surface, with but slight moistening of the undersoil.

It may be stated in general that the irrigator who fails to cultivate soon after each irrigation will make a failure of irrigation. Indeed, in almost any part of the Great Plains, if either irrigation or cultivation must be omitted, it will be better to omit the irrigation than the cultivation for all such crops as admit of cultivation. The case with meadows and with sowed crops in general is somewhat different, the soil being to some extent protected and supported against excessive settling by the general distribution of the plants and roots. It is not improbable, however, that in the case of annuals, as wheat, rye, barley, and oats, it will be found profitable to make the drill rows far enough apart to admit of cultivation while the plants are small. In the case of meadows, especially with alfalfa, the influence of the extensive root growth is such as to keep the soil in condition favorable to rapid growth without cultivation. It is noticeable, however, that even alfalfa shows the marked influence of cultivation where a meadow of this legume joins a cultivated field.

SUBIRRIGATION.

The application of water by means of furrows placed at a considerable distance from the plants to be watered can be beneficial only in soils allowing a considerable lateral movement of the water. This percolation may take place in certain soils through a space of several feet or rods, while in others the influence of the water apparently is not felt for more than a few inches. In cases where the soil and subsoil have a structure such that water moves laterally through them with considerable ease, the theoretically perfect method of applying it is through pipes laid underground below the reach of the plow and perforated, so that when filled the moisture will be uniformly distributed near the roots of the plants. This does away with all losses from evaporation and from saturating the sides and bottom of the open ditches. Unfortunately, however, this method has been found practicable only to a limited extent. Many soils do not transmit the water freely, while others are underlain by a gravelly or open subsoil through which the water escapes downward with far greater rapidity than it can move sideways. Another serious obstacle to the success of this form of irrigation lies in the fact that the little roots of the trees and plants are induced by the moisture to reach out toward the pipes, seeking every crevice or perforation, and soon stopping these up with interlacing rootlets. In California many instances are given where great expense was incurred in laying out an elaborate system of perforated or porous pipes. Irrigation through these was highly successful for one or two years, and then became less so, until the method was abandoned and the pipes taken up or else openings made to the surface, so that the water could come up and spread as from a hydrant over the plat to be wet.

The term "subirrigation" is often applied to the conditions where the subsoil is saturated either artificially or even naturally. For example, many lowlands along streams are commonly said to be subirrigated from the fact that the underlying gravels are filled with ground water which extends up high enough to be available for the use of deep-rooted plants. The word is also applied to similar cases where, by excessive use of water on lands higher up, the low grounds have been so completely filled by seepage that it is no longer necessary to flow water over the surface. This is, however, hardly a proper use of the term, as it can better be confined to the intentional application of water beneath the surface by pipes or similar devices.

The method of irrigating by underground pipes is one that appeals very strongly to the fancy of the novice. It has been repeatedly tried, and in most cases has been abandoned. This does not necessarily prove that the plan is useless or impracticable, and the fact that some have continued its use makes it worth while to describe it and to examine somewhat the conditions of its trials and the probability

SATURATING GROUND.

ılness. The plan is, in general, to place porous drain ›ugh beneath the surface of the cultivated land to be out of the plow and other implements of cultivation, and to ıes of this tile so connected with the source of water sup- y may be filled at will. Reports of the use of this method a state, as noted above, that the roots of the trees and trated the tile at the joints, or at any opening where the l get out, and formed mats of small rootlets within the to effectually obstruct the flow of water. In the gravelly ›ils of Utah it was found that on emerging from the pipe ater was very little inclined to distribute itself laterally, to gravity and went down, so that only narrow strips were ed, and these at considerable depth below the surface, the ıg little inclination to rise above the pipe lines. At the experiment station the › to the surface above ıes, but the spaces be- not well irrigated. A of a tile-irrigated field wed by dark lines the the pipes, while the ; surfaces were entirely

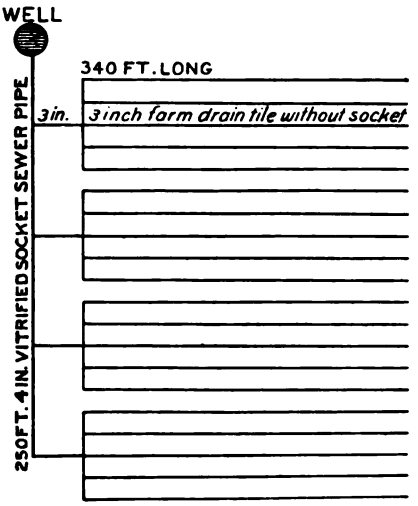


FIG. 7.—Plan of subirrigating system.

ıe County, Kansas, very · results have been re- n pipe irrigation, the ıg been distributed lat- ıat almost ideal irriga- tained. The objection lifornia is one for which .t to conceive an effect- '. It is undoubtedly 'er, that a stoppage in a e easily located, and since the pipes are placed at no great w the surface, it should not be a serious task to remove a ruction. But if the stoppages should be very numerous, › of keeping the lines open might exceed the advantages : the system. In Utah the tendency of the water to go y downward instead of laterally was due to the open, grav- . A consideration of the description of other experiments at the difficulty encountered—that of the water coming to immediately over the pipe lines, but not distributing well nay be overcome by a modification of the work. It appears se experiments the pipes were put in trenches in the sub- › surface cultivation was conducted in the usual way. The ittle opportunity to circulate laterally until it had risen to

the bottom of the cultivated stratum. In the experiments in Osborne County, Kansas, the entire subsoil was broken to the depth at which the pipes were laid. The water moved laterally over the compact, undisturbed lower subsoil and rose to the surface quite uniformly over the entire tract. Possibly if the subsoil in the Wisconsin experiments had been treated in the same way, the results might have been modified and made favorable rather than unfavorable.

The plant of one of the successful tile irrigators of Osborne County, Kansas, Mr. Andrew Linn, is described as follows: The ground was plowed 6 inches deep and subsoiled about 8 inches, altogether stirring the soil to the depth of about 14 inches. The ground was plowed north and south, the tiling laid east and west. The land slopes slightly to the east and south. An arrangement is made to use the plant as a drainage system when there is too much rain. Three-inch tiles are laid 15 inches below the surface and 10 feet apart. Unglazed drain tiles are used, but they are so hard that practically no water passes through the pores, the outlets being at the joints. These joints are closed with cement, with the exception of about an inch on the underside of the tiles. If no part of the joint is cemented, the water flows out too rapidly and is not evenly distributed. Mr. Linn laid and cemented his tiling on 2½ acres in ten days. The ditches for the tiling were made with a lister plow and spade. The pump to supply water to the tiling has a capacity of about 20 gallons per minute.

The diagram, fig. 7, shows the plan of the system. The water is carried from the pump in a wooden conductor and flows into a barrel sunk into the ground about 10 feet away. A 4-inch sewer pipe from this barrel is laid in four sections extending southward across the west end of the plat to be irrigated. At the end of each section the pipe discharges its water into a barrel (not shown in the diagram), also sunk into the ground. From this barrel a 3-inch pipe, 8 feet in length, is laid eastward, where it communicates with a 3-inch pipe laid north and south about 40 feet. To this pipe are connected five 3-inch drain tiles extending eastward entirely across the plat and 10 feet apart. The lot is thus divided into sections, each independent of the others, and facilitating the irrigation of any section at will.

Mr. Linn is satisfied with the results of irrigation with this plant, but as yet no comparison has been made with those obtained by surface irrigation under otherwise similar conditions. The cost of such an arrangement is certainly against it, and will probably, for a long time at least, preclude its use except for gardens or for farming on a very small scale. But the experiments of Mr. Linn and some of his neighbors have shown that with such soil and subsoil as they possess it is perfectly practicable to get a good distribution of water by means of underground pipes. Their plan has been to pump the soil and subsoil full of water during the fall and winter, saturating it to a depth of 6 or 8 feet.

After this it was necessary only to supply the water transpired by vegetation and lost by evaporation, the loss being very small on account of the fact that no crust was formed on the surface, and the flocculent, open structure of the soil was little interfered with by this method of applying water. It remains to be seen whether the plan of cementing the joints of the hard-burned tile, except an inch on the under side, will prevent the entrance of roots to the extent of stopping the circulation of water through the pipes. This method has been used also by Dr. Hudson, of Osborne, who has expressed satisfaction with the results. Other than tile pipes have been used for this purpose. Small pipes made of galvanized iron and perforated with very small holes, or preferably with an open seam, have been used and satisfactory results reported. The following description has been condensed from a statement given by Mr. Alex. Richter, of Hollyrood, Kansas, who has used the open-seam pipes.

The first precaution is to ascertain whether the structure of the soil and subsoil is such that subirrigation is practicable, as it is a useless expenditure of money to lay pipes where the conditions are such that the water will not spread laterally to the plants. In some localities the subsoil is so porous that the water applied beneath the surface sinks immediately and can not be had by the roots of any of the plants except those in the immediate vicinity of the source of supply. This is especially the case on the bottom lands along streams where the surface soil rests upon gravel or beds of sand. Where, on the contrary, the subsoil is comparatively impervious, and above this the structure is such that the water is transmitted horizontally, systems of subirrigation can be introduced to great advantage. For example, the following experiment was tried: During a dry season a pipe 10 feet long was laid 10 inches deep in the middle of four rows of string beans, these being about 5 feet apart. Into the pipe 12 quarts of water were poured, and the same amount was sprinkled on four other rows of string beans in all respects similar to the first. In the case of the rows watered by the pipe the beans did well, while in the other rows they died. The same amount of water was given to each.

In 1895 many experiments were made by different farmers, some putting pipes in rows 5 feet apart, others 8 or 16 feet, and in one case 27 feet. Different depths also were tried, some being 14 inches, others 18, and still others 2 feet. During the first five months nearly all of these were satisfactory, but after that period difficulty was found by the persons who had laid the pipes from 18 to 24 inches beneath the surface. By digging down it was found that the deeper pipes had been placed so low as to be embedded in the clay subsoil, and that this did not allow the water to spread freely. By raising the pipes about 6 inches, well above the top of the clay, the water percolated freely. For vegetables it was found that pipes give the best success when laid from 8 to 10 feet apart, while for orchards a single row of

pipes was sufficient between alternate rows of trees, these pipes being placed from 10 to 12 inches in depth. It was also found that the moisture was rendered more efficient by using fertilizers.

One of the most common mistakes at first made has been in giving too great a slope or inclination to the pipes. If laid on ground which has a decided fall the water runs to the lower end before it can escape in considerable part through the opening along the side. For this reason the pipes should be laid very nearly level, but if a considerable slope can not be avoided it has been found best to have cut-offs in the pipe every 10 or 20 feet to check the flow. Another way is to run the main pipe on the down grade and connect this with irrigating pipes branching from it with suitable valves or cut-offs, so that the water can be turned into the branches. The preferred length of irrigating pipe is about 200 feet. Sometimes this can be connected at both ends with the main supply pipes to advantage. The main supply pipe is proportioned according to the amount of water to be carried. In general for gardens and orchards it is 1¼ inches in diameter. The sheet-iron irrigating pipe leading from this has an open seam along its length and is usually seven-eighths of an inch in diameter, although smaller sizes can be used for flower beds. The cost varies according to the amount used, but in one case where 3 acres were provided, 2 of these being orchard and the remaining acre devoted to potatoes, watermelons, and other vegetables, the entire cost was $63. In this case the watermelons alone paid the cost of the pipe. One man can lay nearly 3,000 feet in a day, covering it up by means of a plow.

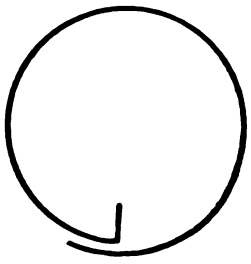


FIG. 8.—Section of open-seam pipe.

There is a notable difference in the distribution of moisture when the subirrigating pipes are laid above the surface of the clay and when they are put down in it. In the first case, when the pipe is buried in the pervious soil slightly above the impervious clayey subsoil, the water spreads laterally upon the surface of the latter, moistening the ground upward while spreading out beneath the surface. In the second case, when the pipe is within the clay, the water can not spread laterally, but rises slowly and moistens only a narrow belt immediately above the pipe, not finding its way as rapidly as in the other case along the surface of the clay.

This difference in behavior is illustrated by an experiment in which two pipes were laid above the subsoil and five pipes below the clay. The two pipes were able to deliver far more water than the five more deeply buried. An examination by a test pit showed that although the surface was dry above the five pipes, there was standing water in the clay. This fairly uniform distribution of water from the pipes *when laid* above the subsoil is said to obviate the difficulty found with *the roots of trees*. The great objection to this form of subirriga-

tion has been that after one or two years the fine roots of plants seeking out the water inclose the conducting pipe and penetrate every opening or crack, finally completely obstructing the flow of water. Where, however, the moisture is distributed uniformly through the soil, the roots are not impelled directly toward the pipe. Cases have been reported where pipe has been used for three years successfully at a distance of only about a yard from a row of trees.

AMOUNT OF WATER REQUIRED.

There are two ways in which quantities of water used in irrigation are expressed. One is in terms of the rate of flow, as, for example, that of a river; the other is in quantities of water, such as would be held by a reservoir. In the first case we speak of a stream as averaging through the month of August 10 second-feet or 500 miner's inches. In the second case we speak of a reservoir as holding, in round numbers, 6.46 million gallons, or 862,000 cubic feet, or 19.8 acre-feet. Each of these can be converted into the other by simple computations. Where water is spoken of according to the rate of flow, the total volume can be obtained only by assuming a certain length of time during which the flow continues. On the other hand, the volume of water, as, for example, that stored in a reservoir, can be converted into rate of flow by figures based upon the number of days or seconds during which the quantity is to be discharged.

In discussing rates of flow of a natural stream, the cubic foot per second or second-foot has been generally adopted as the standard, and is rapidly displacing the older, indefinite term—miner's inch.

The cubic foot per second, or second-foot, is the rate of delivery of a stream 1 foot wide and 1 foot deep, flowing at the average rate of 1 foot per second. The quantity is, of course, independent of the shape or velocity of the water; a second-foot will be delivered by a pipe 6 inches in diameter in which the average flow is a trifle over 5 feet per second, or by a ditch having a cross section of 4 square feet and a sluggish current of only 3 inches per second.

The miner's inch is a unit adopted for convenience by the hydraulic miners of the West, and, being easily arrived at through rough devices, has been largely employed throughout the arid region in estimating the quantities of flowing water. The chief objection to it is its indefinite character. One miner's inch may be 20 or 25 per cent larger than another, although both are measured according to established rule or customs. In early days, when water was abundant and it had little value, there was no especial demand for accuracy in its measurement, and the crude devices sufficed for all practical purposes; but when the streams came to be used for agriculture and it was appreciated that values resided in the flowing water rather than in the land, it made considerable difference to a farmer whether his miner's inch of water was large or small. To avoid confusion and litigation, the term "*miner's inch*" has therefore been largely done away with

and quantities are given in fractions of a second-foot. In California the miner's inch is now given as one-fiftieth of a second-foot, while in Colorado and many other of the Rocky Mountain States it is nearer the fortieth part of a second-foot. In other words, the Colorado miner's inch is considerably the larger.

The second method of stating the quantity of water—that by actual volumes rather than by rate of flow—is in all respects the more accurate and desirable, and is the only practicable means in localities such as those on the Great Plains, where water must be pumped or stored and is not running continuously to waste when not used, as is the case along the larger streams of the arid region. The units employed may be the gallon, the cubic foot, or the acre-foot. The United States gallon, as defined by statute, contains 231 inches; 7.48 gallons make a cubic foot, or 1 gallon is 0.13368 of a cubic foot. The chief disadvantage of the gallon as a unit is that it is too small and requires large figures to express the amount needed for irrigation. It has also the additional disadvantage that there are other gallons of other sizes in use, so that confusion occasionally arises.

The cubic foot is a definite quantity and is very convenient for use in computations of the amount of water required. By its use the capacity of reservoirs can be readily computed, since their dimensions are usually expressed in feet. It is, however, like the gallon, too small for convenience in many estimates, and in practice it has been largely replaced by the acre-foot. This latter term implies a quantity equivalent to the amount of water covering 1 acre to the depth of 1 foot. In other words, 1 acre-foot equals 43,560 cubic feet. This quantity—an acre-foot—does not imply that the water must be spread out 1 foot in depth, for the 43,560 cubic feet can be placed in a reservoir of any shape and still be an acre-foot. It may be held, for example, in a pond 100 feet square and to a depth of a little over 4.3 feet, or it may be in a tank 20 by 50 feet and 43.56 feet deep. There is a convenient relation between the acre-foot and the cubic foot per second, or second-foot. The latter flowing for one day (twenty-four hours) very nearly equals 2 acre-feet; that is to say, a stream 1 foot wide and 1 foot deep, flowing at an average velocity of 1 foot per second, will in one day, or 86,400 seconds, cover a surface of 1 acre to a depth of very nearly 2 feet.

The term "duty of water" has been employed to express the relation which exists between the quantity of water used and the area of land irrigated. For example, if a stream of water equivalent to 1 cubic foot per second irrigates 100 acres, the water duty at that place is stated as being 100 acres to the second-foot. This water duty may be arrived at from two opposite directions. First, as given above, by taking actual instances of the measured amount of water applied; and second, by starting at the other end and estimating the theoretical amount which the plants require and the quantity which must be *wasted in wetting* the ground before the water can be available for the

need of the plants. Neither of these is wholly satisfactory, and there has not as yet been obtained a sufficiently large body of facts to enable conclusions of general applicability to be drawn. Taking any one crop through successive years, the amount of water actually used varies so widely that it is doubtful whether any figures yet published can be implicitly relied upon.

A large number of experiments have been carried on, not only in Europe but in this country, to show the amount of water exhaled by plants. The results of these, as above stated, are discordant, but as a rough statement it may be said that the plants have transpired during their growth a weight of water from 300 to 500 times that of the weight of dry matter. In this country various agricultural stations have obtained and still are obtaining data bearing upon this point. Among the best of the published results are the series of experiments conducted by Prof. F. H. King at the Wisconsin agricultural station. These are of particular value in this connection as showing the amount of water required by plants even in a humid climate. The results of the observations for 1892 show the following amounts of water consumed per pound of dry material produced:

Crop.	Water consumed.
	Pounds.
Barley	375
Oats	526
Corn	317
Clover	564
Pease	477

The data given above have been combined with those obtained for 1891 and computed in other units, giving the corresponding depth of water used in the production of the plants. These results are shown in simplest form in the following table:

Crop.	Year.	Water consumed.
		Inches.
Barley	1891	13.2
Do	1892	23.5
Oats	1891	19.7
Do	1892	19.0
Corn	1891	26.4
Do	1892	25.1
Clover	1892	29.7
Pease	1892	16.9

From the above table it is to be observed that the least amount of water used was by the barley in 1891, and it should be noted that the product for this year was only about half that for 1892, while nearly double the amount of water was used. It is probable, therefore, that if the barley had received or used as much water as the same crop in 1892, the production of dry matter would have been greatly increased.

It has been found that there is a great range in the amount of water employed by various plants in the process of building their tissues, and that not only do the different species stand widely apart in this respect, but even individuals of any one species at the successive stages of life or with alternations of climatic conditions transpire water more or less freely. As previously noted, the experiments, when reduced to a common basis, show a wide range in results, depending largely not only upon the conditions under which the tests were carried on but also upon the assumptions necessarily made in reduction to the same form of statement. Thus the water used by a crop of wheat is from 9.3 to 29.8 inches in depth, averaging 17.9 inches; by barley, from 4 to 30 inches; the same experiments in successive years obtaining 13 and 23.5 inches, the difference, however, being in part accounted for by the increase in yield.

In actual crop production, however, it is necessary not only to satisfy the thirst of the plant but also to fill certain demands of the soil necessitated by its composition, structure, and exposure to the air. A certain amount of water must be given to the soil before the plant can obtain any for itself, and, according to the skill of cultivation, more or less of this water will be taken up directly by the air or by weeds. The process of getting the water to the crop, usually in open-earth channels, is also more or less wasteful, so that beyond the plant's needs there is always to be added a variable percentage to cover these various losses. Many of these losses may be reduced or prevented by more perfect systems of irrigation and cultivation, but there is always a limit to expenditures in this direction set by the market value of the product. In other words, it will not pay to push water economy in this direction beyond moderate efforts.

To obtain valid conclusions as to the total amount of water required by the plant, together with that portion lost in transit in the irrigating channels and in the soil while waiting for the demands of vegetation, it is necessary to resort to the results of field tests made in various localities under local conditions of soil and climate. There are, unfortunately, comparatively few data as yet sufficiently complete for generalization, and these, as might be expected from an analysis of the matter relating to plant transpiration, offer wide discrepancies.

Experimental data are still lacking as to the exact amount of water required for the proper moistening of plains soils to any depth. It is not unusual with alfalfa to apply 6 inches of water, or over 680 tons

per acre, at a single irrigation, but with the usual field crops it is probable that 3 acre-inches at an application is more usual than a larger quantity. Experience of irrigators generally favors the application of enough water to moisten the soil to a considerable depth, say 1½ to 2½ feet, and then by cultivation producing a mulch of fine soil on the surface to retard evaporation, thus retaining the water of a single irrigation for the use of the deeper roots of the plants for a considerable period, rather than the more frequent application of small quantities, which, by moistening only that portion of the soil very near to the surface, encourages the growth of roots in that portion of the soil which soon becomes dry. Such irrigation leads to spasmodic and irregular growth and often to serious injury to the plant from drought, even though very frequently watered. For general purposes it is undoubtedly the best plan to have the subsoil well moistened early in the season and to keep up the supply of moisture by such copious subsequent irrigation as will encourage the development of deep roots and maintain the uniform maximum growth of the plants.

A convenient figure in estimating the quantity of water to be applied to orchard and ordinary crops at a single irrigation is 100,000 gallons per acre. This will allow of some loss by seepage in the ditches, and usually moistens the soil to a good depth if judiciously applied, and can by the furrow system generally be so applied as to leave the soil in good condition for growth.

The quantity of land which may be irrigated by a single man in a given time is exceedingly variable, and depends greatly upon the skill with which the land has been graded and the ditches have been laid out and constructed. Twenty acres per day may be as easily irrigated under some conditions as 1 or 2 acres under other conditions. In garden operations, of course, the areas covered are usually much less than in the big fields, and a man may sometimes spend a whole day on very much less than an acre and have no reason to chide himself for inefficiency.

WINTER IRRIGATION.

On the plains the winter and early spring months are usually dry, and the soil is sometimes almost as devoid of moisture at the opening of spring as during subsequent droughts. This powdery soil is easily worked, and some have thought it in favorable condition for the reception of seed, and that copious watering later would be sufficient to insure the full benefit of irrigation. But disappointments have sometimes resulted, scarcely better crops being realized than where no water was applied artificially. On the other hand, where similar soil has been thoroughly moistened by the late winter or early spring rains, or by winter irrigation, the fertility of the soil has been amply demonstrated. Whatever may be the explanation of the fact, it has been

found by nearly all observant irrigators of the plains that winter irrigation, thoroughly done, serves very well the double process of fertilizing and moistening. Mr. Perry states that after his eight years of extensive experience in irrigation, he has had the best average results where he has thoroughly saturated the soil to a depth of 2 or 3 feet during the fall or winter or very early spring, and then has cultivated his crops on this land without subsequent irrigation. Mr. C. B. Huffman, of Enterprise, Kansas, has found that land thoroughly irrigated and well cultivated during the season of 1895, and afterwards sown in wheat, produced suprisingly well in 1896 without any irrigation after the wheat was sown, while similar land that had not been irrigated gave a very poor yield. The general experience of orchardists favors winter irrigation. Not unlikely, future practice in the application of water will consist in thoroughly wetting the soil during the winter and in such subsequent irrigation as may be found desirable to maintain the maximum growth, the larger quantity of water being applied in the winter, when evaporation is at a minimum.

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1894.

Report on agriculture by irrigation in the western part of the United States at the eleventh census, 1890, by F. H. Newell, 1894, quarto, 283 pp.

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Contains results of stream measurements at various points, mainly within the arid region and records of wells in a number of counties in western Nebraska, western Kansas and eastern Colorado.

1896.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Economic geology and hydrography, 1896, octavo, 804 pp.

Contains papers by G. K. Gilbert on the underground water of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois; and by N. H. Darton on a reconnoissance of the artesian areas of a portion of the Dakotas.

Artesian well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 250 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

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Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896, octavo, 864 pp.

Contains papers by H. E. Gilbert on the underground water of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois; and by W. H. Norton on a reconnaissance of the artesian areas of a portion of the Dakotas.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 30 cents.

Gives a description of the geologic structure of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 206 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

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WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phoenix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth,
7. Seepage waters of northern Utah, by Samuel Fortier.
8. Windmills for irrigation, by E. C. Murphy.
9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker.

In addition to the above, there are in various stages of preparation also other papers relating to the measurement of streams, the storage of s unused available from underground sources, the efficiency of windmills, t pumping, and other details relating to the methods of utilizing the water of the country. Provision has been made for printing these by the followi in the sundry civil act making appropriations for the year 1897-'97:

Provided, That hereafter the reports of the Geological Survey in relati gauging of streams and in the methods of utilizing the water resources printed in octavo form, not to exceed 100 pages in length and 6,000 copie [illegible] 1,000 copies of which shall be for the official use of the Geological 1,500 copies shall be delivered to the Senate, and 3,500 copies shall be del the House of Representatives, for distribution. (Approved, June 11, 1896; vol. 29, p. 453.)

Applications for these papers should be made either to members of Cong

The Director,
United States Geological Survey
Washington

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 6

UNDERGROUND WATERS OF SOUTHWESTERN KANSAS.—HAWORTH

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1888:

1888.

First Annual Report of the United States Irrigation Survey, 1888, octavo, 179 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey; a preliminary report on the organization and preservation of the survey of the arid lands for purposes of irrigation, and report of work done during 1888.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statements of the Director of the survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains a report upon the location and survey of reservoir sites during the fiscal year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 9 plates and 180 figures.

Bulletins of the Eleventh Census of the United States upon Irrigation, prepared by F. H. Newell, quarto.

No. 97, Irrigation in Arizona; No. 98, Irrigation in New Mexico; No. 99, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 165, Irrigation in Nevada; No. 172, Irrigation in Oregon; No. 195, Artesian wells for irrigation; No. 196, Irrigation in Washington.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92; Part IV, Irrigation, 1893, octavo, 482 pp.

Consists of three papers: Water supply for irrigation, by F. H. Newell; American engineering and engineering results of the Irrigation Survey, by Herbert M. Wilson; Construction of topographic maps and selection and survey of reservoir sites, by A. H. Thompson. Illustrated by 47 plates and 116 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893, octavo, 108 pp., 12 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

(Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATERS OF SOUTHWESTERN KANSAS

BY

ERASMUS HAWORTH

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, April 9, 1897.

SIR: I have the honor to transmit herewith a paper entitled Underground Waters of Southwestern Kansas, by Erasmus Haworth, geologist of the University Geological Survey of Kansas, and to recommend that it be published as the sixth number of the series of Water-Supply and Irrigation Papers.

The field work upon which this report is based was carried on by Professor Haworth during the summer of 1896 in connection with the investigations of the Division of Hydrography. Its object was to obtain detailed information concerning the amount and quality of the underground waters, in order to throw light upon the problems connected with the utilization of these in the development of agriculture upon the Great Plains. Although the investigations were of necessity confined to a somewhat limited area, the conclusions have a general value in showing the limitation to which similar areas of the public domain are subject.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

UNDERGROUND WATERS OF SOUTHWESTERN KANSAS.

By ERASMUS HAWORTH.

INTRODUCTION.

SOURCE AND DISPOSITION OF WATER.

All terrestrial water comes primarily from the ocean, whence it is taken by evaporation. It may then be carried by the winds to the farthest portions of the dry-land areas and deposited on the surface of the ground, principally as rain, but partially as snow, mist, fog, or dew. No ground water available to man in any portion of our globe has had or can have any other ultimate source, whether we consider the water near the surface or that more deeply buried.

Water thus left upon the dry land deports itself in a variety of ways, dependent upon the different conditions under which it is placed. A large portion is evaporated directly from the surface before it has had an opportunity to run off or to be absorbed by the soil or to penetrate to greater depths. Of that which is absorbed, large portions are ultimately dissipated by evaporation from growing vegetation. A second portion runs from the plains and hillsides down into the streams and rapidly returns to the ocean whence it came, while a smaller portion more gradually works its way into the same streams by seeps and springs and reaches the same destination. Other portions soak into the soil and ground and serve as a permanent supply of moisture in the soils and surface coverings; while still other but lesser parts sink below the surface soils and below the roots of vegetation, where they remain a constant source of available water existing in sufficient quantities to more than saturate the ground, and hence become available when drill or spade penetrates it. Each of these several methods of deportment is important to the student of hydrology, and may therefore briefly be considered here.

SURFACE EVAPORATION.

A large but varying proportion of the total rainfall is evaporated from the surface before it has had an opportunity to run off or to be absorbed by the ground. The proportion thus evaporated varies greatly in different parts of the world and under different conditions of season and tillage of the soil. The dry, hot winds, the scorching

rays of sunshine, and often the hot soil itself cause evaporation. Summer seasons and arid climates are most favorable for rapid evaporation. In countries where the rainfall is light, the climate warm, and the soil barren of vegetation the little rainfall that does occur is largely evaporated, but in the lowlands adjacent to large bodies of water in cool climates, where the precipitation is abundant, the evaporation is very light. The character of soil and soil covering also has a great influence upon the rate of evaporation. A mulch of any character whatever greatly retards the evaporating action. In cultivated fields a thin mulch of dust or of straw or other litter has this retarding influence, making the condition of tilth an important factor in determining the extent of evaporation.

RUN-OFF.

The water which flows from the plains and hillsides down into the streams has been called the "run-off." The percentage of total precipitation thus disposed of depends upon a number of conditions, such as aridity of climate, amount of moisture already in the soil, rapidity of precipitation, and the general character of the ground upon which the precipitation falls.

Other conditions being equal, the drier the soil the greater its absorptive powers. An ordinary rain falling upon a dry, cultivated field will be almost entirely absorbed; but if the ground is already charged with moisture nearly all the rain will run off the surface and be carried away through the ordinary drainage channels. The per cent of the total rainfall which joins the run-off in humid climates is therefore much greater than in arid climates unless other conditions modify the results. In general, therefore, the proportion of the total rainfall which may be counted on for filling reservoirs in arid and semiarid climates is much less than in humid climates.

The rapidity of precipitation is an important factor in the calculation of the relative percentages of rainfall and run-off. A mild rain continued through many hours will give but little run-off, while the same amount falling in a fourth or an eighth the time will give a greatly increased run-off. Unfortunately the climatic conditions are such in nearly all the arid portions of the world that what little rain does fall comes in the form of hard, driving storms. On the Great Plains of America it is by no means unusual for a 2-inch rain to fall in as many hours, while instances are of yearly occurrence in which 4 inches or more falls within one hour. Under such conditions almost all the water runs off, except in the most sandy places.

The most important of all the conditions named affecting the run-off is the character of the ground upon which the water falls. A loose, porous soil will absorb a large portion of a rainfall, as will also a sandy soil, while a close, compact soil sheds the greater part of it. Here the geologic conditions of a country become important. An

a composed principally of a close-grained shale, and a soil result-
; therefrom, which generally has a compact clay subsoil, has inferior
orptive properties, while one composed principally of sandstone
l sand will let but little water run away.

The flood plains of rivers frequently have little power of absorption.
times of overflow a thin layer of a fine-grained sediment is depos-
l, which is partially cemented by an organic mucilage produced by
decomposition of organic matter of one kind or another. This
terial is almost entirely impervious to water, a thin layer of it
ng sufficient to prevent downward percolation, no matter how sandy
soil is below. Illustrations of such conditions may be found in
ny places along the valleys of the Arkansas River, the Rio Grande,
l other streams, particularly those which rise at high elevations
l have a strong velocity throughout their upper course and a low
ocity farther downstream.

n times of freshet the muddy water drawn from the streams into
igation ditches always deposits a film of sediment over the bottom
the ditch, provided its fall is not too great. This fills the little
ces between the grains of sand in the soil and renders the ditch
ter-tight. Likewise, when such a stream overflows its banks the
ddy water deposits a corresponding film of fine mud over nearly
whole of the valley covered by the water, a filling-in process which,
ntinued from century to century, forms an important part of the
uvial soils of the valley. Along the Arkansas Valley such an accu-
lation of silt has produced beds varying from 1 to 6 or more feet
thickness, a covering that will scarcely let water pass through it
til it is loosened by cultivation. The common method of making
ervoirs in the valley is based upon the impermeability of the soil
water, and such reservoirs require much less puddling to make
m water-tight than those in localities where more sand is present in
soil.

Along the Rio Grande the well-known adobe soils are of the same
neral character. The adobe is a thin covering, generally from 1 to
et thick, along the river flood plain, resting upon a mass of sand
sandy soil. A pool of water in such an adobe soil will remain in
ce until evaporated; but should a hole be made through the adobe
ering into the sand below, the water will quickly sink.

Many of the upland areas in different parts of the world were at
time the flood plains of rivers, and were more or less covered
h such fine sediments, and now constitute close-grained, compact
ls, allowing but a small amount of water to penetrate them. Wind
ion, too, often helps to produce an impervious soil by blowing the
er particles of dust away from some localities and lodging them in
ers. Generally there is a compensating action here, for the
rser materials left behind form a covering with a high degree of
sorptive power, and therefore decrease the amount of run-off.

SOIL MOISTURE.

A portion of the rainfall is consumed in keeping the soil moist. The ground can yield no water unless a portion of it is more than moist. It is not the amount of water a soil or stratum holds that is important, but the amount it will give up when penetrated. In recent years considerable work has been done in determining the capacity of different soils to hold moisture. This is an important investigation in connection with agriculture, and in calculating the percentage of run-off, but in connection with the problem of available underground water supply it is of less value, because it does not show the proportion of water that will be given up when the materials are punctured by the drill. In fact, the best character of ground for producing a good water supply is one which will not admit of a high percentage of soil moisture, but rather a soil that will readily yield almost all its moisture to the general water reservoir below. A sandy soil or a loose, open sandstone will gather large quantities of water from the rainfall and pass it down to the reservoirs below, where it is held available, while a soil with a greater capacity for holding moisture will yield less to the pump.

AVAILABLE GROUND WATER.

Throughout the humid regions of the world, with few exceptions, water can be found everywhere within a few feet of the surface, so that it is the common experience to obtain water for domestic uses by digging from 5 to 100 feet. This condition is so common that the masses of mankind throughout the humid areas of the world have come to look upon it as certain, and rarely give it any special consideration, and the industries and operations of civilized man are based upon a belief in the perpetual continuance of such condition.

The available ground water in all localities and under all circumstances is the residue of the rainfall after the portions mentioned above—the evaporation, the run-off, and the soil moisture—have been deducted. Each of them must be supplied, in whole or in part, before any available ground water can exist. In many places there is an underground movement, so that the available water under a given area may have fallen only in part as rain upon the surface at that place; yet somewhere and sometime it must have fallen as rain, some of which was evaporated, some carried off by the drainage, some held as soil moisture, and the remainder sunk below the surface, below the reach of growing plants, and held in an underground reservoir, inviting the spade or the drill to discover it and the pump to lift it to the surface. But even yet the wastes are not satisfied, for portions of this underground water are carried by underground drainage to the surfaces of ravines and bluffs, bursting forth as springs, and thus joining the general body of the run-off.

GEOLOGIC CONDITIONS GOVERNING GROUND WATER.

The stratified rocks of the earth are a heterogeneous mass of matter arranged in layers one above another. The strata are not coextensive with the surface of the earth, but some of them occur at one place and others at other places, each lapping under or over its neighbor, quite like shingles on a roof. Some of the strata are composed of loose, porous material, such as sandstone or badly fractured limestone, so that water can readily pass through them. Others are formed from the accumulation of finer sediments, such as clay and the finest of silt, while still other parts of the earth are composed of the crystalline rocks, such as granite, porphyry, and syenite. No substance known forming a constituent part of the earth is entirely impervious to water. The solid granite and the compact limestone and marble alike have moisture within them, commonly called "quarry sap," showing that water penetrates them. Compact, plastic clay is perhaps about as good a nonconductor of water as is known, while beds of sand and gravel are at the opposite extreme, allowing water to pass through them with relatively little resistance. The surface of the ground almost everywhere has a covering of residual soils, sands, and clays, varying from a few inches to many feet in thickness. This usually has high absorptive power for water, so that a large amount is received from the rains as they fall.

When the surface water comes in contact with the porous strata it is absorbed and immediately begins moving downward, or as nearly in that direction as possible. Sooner or later it comes in contact with an impervious stratum below, and thereafter can only move laterally down the incline of that surface. The rapidity of motion will now depend principally upon two conditions—the angle of inclination of the impervious surface and the degree of porosity of the material through which the water moves. Should this be a mass of gravel or sand or porous sandstone, the motion will be sufficient to be easily detected, and somewhere farther down the water will reappear as springs or seeps, supplying the streams with "living" water. It matters not whether this porous stratum is on the surface of the ground in the form of a soil covering or whether it is deeply buried by impervious layers, the water movement within it will be practically the same. When the latter condition prevails and a sufficient head is produced, a well drilled through the upper and impervious layers allows the water to rise through the drill hole, and an artesian well results. Where the porous layer is on the surface, as is often the case on the Great Plains, no pressure or head can be produced, for the water is simply running down an inclined surface with nothing above to prevent it from rising, so that it would be comparable to water flowing down a wide open trough.

A good illustration of this latter condition is found near the University of Kansas, at Lawrence. In 1893 the university authorities

decided to own their own water supply. An investigation was therefore made to ascertain whether a sufficient supply could be had within a reasonable distance of the buildings. It was found that on the south side of the hill a large amount of débris produced by the decomposition of the limestone and shales of the hill had accumulated on the hillside, and that it was well charged with water. Fig. 1, drawn to scale, shows the conditions. The hill is composed principally of a fine-grained impervious shale, with a limestone mass (A) on top. At the boiler house, 300 feet south of the brow of the hill, the débris was found to be 40 feet deep. A well dug here (B) during the driest part of a dry year showed that the amount of water was not very considerable. At points farther down the hillside the water was more abundant. Finally, a large well was put down at the point C, 1,000 feet south of the brow of the hill, and galleries about 6 feet in height were run both east and west, just on top of the undecomposed shale, to intercept the

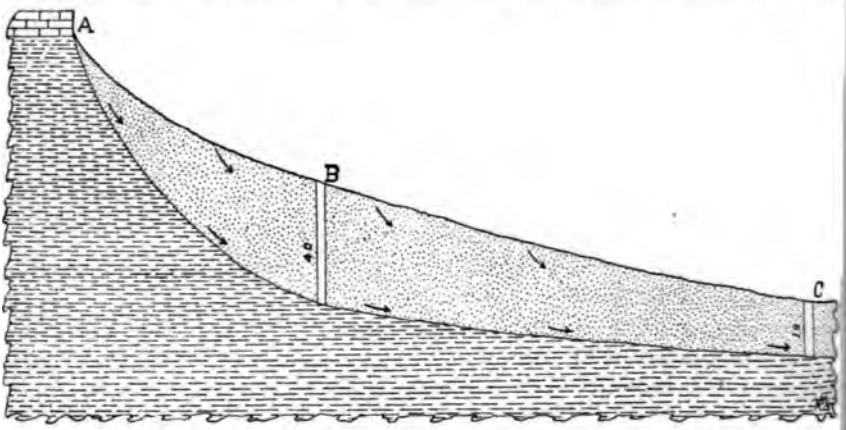

FIG. 1.—Diagrammatic section of hill at Lawrence, Kansas.

water as it moved down the slope and drain it into the well. It was reasoned that this greater distance from the summit of the hill was necessary because the gathering area above the boiler house was so limited that an insufficient amount of water would be obtained at that point, but that with the added distance to where the well was finally located a gathering area of sufficient extent was passed, considering that the average rainfall at Lawrence is a little more than 35 inches annually. Southward the thickness of the débris gradually decreases, so that a mile away it is only an ordinary soil above the undecomposed shale. Were the débris a mass of coarse sand, similar to that so often found in the western part of the State, without doubt the water would soon all run down the hillside and appear as springs in many places; but the débris from a mass of shale is principally a clay, which lets the water through it very slowly, and therefore its southward movement *is so* slow that little reaches the extreme southern limit of the débris.

et in the vicinity of the well a water supply is found sufficient to oduce 5,000 gallons a day almost all the year, and 10,000 in wet eather, an amount which could be increased indefinitely by extending e east-west galleries.

Here we have a good illustration of the underground water plane aving a very concave surface facing upward. Instead of the water ing in the form of an underground lake, with a level surface, it is a ass of water held in the clay in such a manner that its upper sur- ce is nearly parallel with the highly inclined surface of the ground. 'e may speak of the clay within the body of water as being more an saturated, using the term saturated to mean holding a water ntent just equal to the largest amount the clay can hold without eing compelled to give up a part of it whenever an opening is made to it. When the clay is in this condition and more water is added it, this extra amount will run out into the opening made.

As the well at the point C was being dug it was noticed that the lay was moist almost from the surface, but that no water came into he well until it had reached to within about 6 feet of the undecom- osed shale. Here the point of saturation was reached, and any reater depth passed clay which was more than saturated, that is, ad more water within it than it could hold back from running into he well. This extra amount in excess of saturation is the available ater in all cases. It is that which has an underground movement, nd which is available in so many parts of the world as supply or man.

In the area under consideration, in the western part of Kansas, we nd conditions remarkably similar to those just described for Law- ence. We have a broad expanse of country on which rain falls, and as been falling since the close of Tertiary time, and possibly longer. he surface of the ground is usually well adapted for the absorption f large amounts of this rainfall. After absorption the water obeys he laws of gravity and moves downward, except such portions as re used by the growing vegetation and for moistening the soil. The emainder continues downward until it meets with a stratum which s so nearly impervious that it is almost entirely arrested, after which moves slowly along the upper surface of the impervious floor in a anner similar to the water in the clays at Lawrence. This floor es at varying depths in different parts of the Great Plains area, ometimes so deep that the upper surface of saturation can not be eached within 200 feet, while at other places it comes entirely to the urface of the ground.

LOCATING GROUND WATER.

The ability to locate ground water is a qualification desired by any and possessed by few who do not understand the principles overning ground-water movement. The "open sesame" of myth- al times gave way to the wand of the wizard, an instrument still

employed in many parts of the civilized world, usually in the form of a forked twig from the bough of a tree, but occasionally a branch, forked or otherwise, from the bough of some particular tree or shrub. In a majority of cases, predictions in humid climates made by the use of the wand prove to be correct unless impervious material is met with in digging, for the whole ground is more or less saturated with water.

As above stated, the water which falls as rain or snow is partially absorbed by the surface materials and starts on its downward course under the influence of gravity. The laws governing its movements are identical with those which govern the movement of surface water. When impervious material is reached the water is arrested in its movements unless it can pass down an inclined plane, the surface of the impervious mass. If limestone or granite or other solid rock is reached, the water will follow the fissures in the rock, and will often ultimately be brought to the surface as springs along ravines and hillsides.

The proper way of considering the matter is to look upon the whole of the subsurface part of the ground as containing available water except where impervious materials exist. If a heavy bed of shale is found which is close-grained and compact, it is useless to look for water within it. Many examples are met with in mining operations which illustrate this, a few of which may be cited. In mining for rock salt at Lyons, Kansas, a mass of loose surface material was found to extend downward for nearly 300 feet. This was so thoroughly charged with water, particularly near the bottom, that it interfered seriously with the mining. Below this a bed of fine-grained Permian shale was reached, in which the salt is found. This shale is particularly impervious to water, as is shown by the fact that no water has come into the shaft since the surface water was shut out, although the shaft is 1,000 feet deep. Similar conditions are found in drilling for oil and gas in Kansas and elsewhere. Often a heavy bed of shale or a solid body of limestone is met which has no water whatever within it. The gas fields of Indiana likewise have similar conditions. Here, after passing through a few hundred feet of water-bearing materials, a 300-foot bed of fine-grained solid shale is found lying immediately over the Trenton gas-bearing limestone. This shale is impervious to water, and lets none of the surface water pass downward through it, and none of the deeper-seated water pass upward. It is so dry that water has to be added while drilling in it.

The existence of such shale beds, or beds of other impervious materials, can generally be recognized by the geologist by surface conditions if he is familiar with a sufficiently wide range of country; otherwise the drill is the only means of discovering it. Wherever large masses of such materials, or of granite or other solid and impervious crystalline rock, cover a wide extent of country, the only hope

f finding ground water is along the ravines and hillsides, where a sufficient amount of surface débris has accumulated to hold the local rainfall, as already explained for Lawrence, Kansas.

Where limestone is the prevailing rock it usually has so many fissures that water finds its way into them and works downward and out through openings along the creeks and bluffs, so that much of it finally joins the run-off. Under such conditions well digging is hazardous, often resulting in failure. It is here that the term "vein" of water is applicable, a term which is generally used indiscriminately, whether the water occurs in veins or in broad beds of water-bearing materials. Here the "water witch" is in most demand.

In such countries careful observation of surface conditions will usually yield good results. The water slowly but surely dissolves the limestone, so that a falling in of the materials above to an appreciable degree is frequently noticed, often resulting ultimately in the production of a ravine of considerable size. The number of fissures along the bluffs will give some idea of the abundance of fissures generally, and therefore of the probability of one being found where a well is desired. But best of all and surest of all in such localities is it to search for places where the surface covering is heavy enough to hold the surface water. Few places in humid climates can be found where this is not sufficient for all ordinary purposes. By far the greater proportion of all the well water and spring water of the world comes from this source. On the great plains of western Kansas the surface covering is generally abundant and heavy, and holds surprisingly large quantities of water. To give a detailed description of the water supply of a limited portion of the plains of Kansas is the object of this paper.

GEOGRAPHY OF THE AREA.

The area discussed in this report is located in southwestern Kansas, and covers 1 degree each of latitude and longitude. It is bounded on the east by the one hundredth meridian west from Greenwich, on the west by the one hundred and first meridian, on the south by the thirty-seventh parallel, and on the north by the thirty-eighth. It includes all of Meade County, nearly all of Seward, Haskell, and Gray counties, about one-third of Ford County, and one-fourth of Finney County. Its eastern limit is approximately the line between ranges 24 and 25 west of the sixth principal meridian, and that on the west side near the middle of range 34. Its south line is about the middle of township 35, and the north line is the line between townships 23 and 24. It is, therefore, approximately 56 by 69 miles square, equal to about 3,864 square miles, or about two and a half million acres. It corresponds to four of the United States Geological Survey quadrangles, known as the Meade, Dodge, and Garden, and the one south of the Garden, not yet surveyed.

The Arkansas River enters this area at the northwest and flows

across it in a southeasterly direction, passing out 16 miles south of the northeast corner. The Cimarron River passes across the southwest corner of the area, leaving the State near the middle of the southern boundary, but flows near the south line throughout the remaining distance to the one hundredth meridian. There is but one other stream of any considerable consequence in the area, Crooked Creek, a stream which rises near the central part and, after meandering in a manner indicated by its name, enters the Cimarron just south of the State line, near the southeast corner of the Meade quadrangle. Aside from these streams, a few lesser ones occur in the northeastern part of the Dodge quadrangle, which drain northeast into the Pawnee—such as Duck Creek, the Sawlog, and the Buckner.

A fair idea of the elevations of the area under consideration may be gained from the following data: The Arkansas River on the east border is 2,460 feet above sea level, and at Sherlock, in the extreme northwestern corner, its level is 2,860 feet, the river making an aggregate fall of 400 feet while crossing the area. The bluffs immediately north of the river at Dodge are 2,600 feet high, while in the extreme northeastern part the elevation is only 2,460 feet, or the same as that of the river at Dodge. The southeastern corner of the Meade quadrangle, near Englewood, has an elevation of 1,960 feet, and the southwest corner of the area, about 4 miles west of Liberal, has an elevation of approximately 2,900 feet. It is therefore a plain, or table-land, with the western edge nearly horizontal, sloping to the east with an average rate of about 7.1 feet per mile along the north end and nearly 17 feet per mile along the south.

The eastern border, therefore, slopes toward the south, making the southeast corner much the lowest part of the whole area. The elevations immediately adjacent to the Arkansas River are greater than can be found either north or south, except those in the southwest corner of the area, where we have higher land than exists along the river.

PHYSIOGRAPHY OF THE AREA.

GENERAL CONDITIONS.

The general physiographic features are those of a broad peneplain sloping gently to the east, into which, at different places, channels have been worn by recent processes of erosion. All the streams with their tributaries, except Arkansas River, appear to be mere channels cut down into the general plain. The Arkansas, on the contrary, throughout the most of its course within this area, seems to be a channel cut into a ridge extending from west to east, as though at one time the river had built its banks higher than the land on either side and had subsequently deepened its channel and produced a flood plain averaging more than 2 miles in width. Both east and west of here the conditions become more nearly normal, as is shown by tributaries entering the river from both sides.

North of the river, where the surface slopes to the northeast, the northeastern drainage often approaches to within a mile and a half of the Arkansas River. The almost complete absence of any tributaries entering the river from the north is remarkable. On the south the conditions in this respect are not quite so extraordinary. A strip of country varying in width from 4 to 18 miles is covered with masses of sand, which have been blown by the winds in recent times into exceedingly irregularly shaped hills and hillocks. Throughout a part of this area tributaries of the river rise from 6 to 10 miles south and work their way through the sand hills to the river. In most instances, even on the south, the drainage toward the southeast approaches surprisingly close to the bluffs on the south side of the Arkansas River.

In the northeast portion of the Dodge quadrangle the drainage is all to the northeast, the waters of which ultimately enter Arkansas River, near Larned, through the Pawnee. As the surface is inclined fully 10 feet to the mile, these little tributaries have cut their channels from 100 to 150 feet deep, and present sometimes almost precipitous bluffs, which bound the narrow flood plains of the different streams.

Over all the southern two-thirds of the area under consideration the drainage is entirely to the southeast. The inclination of the surface in this direction is quite rapid, averaging along the line from Santa Fe through Meade to Englewood more than 16 feet to the mile. The general appearance of the whole country is that of a broad, level plain, with almost no variations of any kind, except here and there where a tributary of the Cimarron or of Crooked Creek has worn its channel downward into the plain. These channels are usually quite narrow, with very rugged bluff lines, produced by the channels being cut to depths of 100 to 150 feet, and in extreme cases to greater depths. When one is standing on the plain the whole country appears to be level, but to one in a valley of a stream the bluff lines are so rugged and so varied that almost a mountainous aspect is presented. This is particularly the case along the Cimarron in the vicinity of Arkalon and along Crooked Creek and its tributaries almost anywhere below Meade.

CIMARRON RIVER VALLEY.

The valley of the Cimarron rarely exceeds 2 miles in width throughout its course across the Meade quadrangle, but it has scarcely passed beyond these limits when it suddenly widens to an unusual extent. Beginning a few miles above Englewood, it has a valley more than 5 miles wide. North of Englewood is a valley, or an area which seems to be a valley of erosion, 10 or 12 miles wide, now covered to varying depths with sand which has a very little silt and soil intermingled. Such a wide valley appearing so suddenly along the course of a stream is very interesting, as its origin is hard to determine. The bluff lines forming the western and northern boundaries correspond remarkably

with those on the south side of the Cimarron. The general appearance of the valley, only a small portion of which is west of the one-hundredth meridian, is that of a valley of erosion, with the sandhills representing the residual sands left behind after the surface drainage had carried away the finer silt and clay.

The Cimarron seems to have reached base-level and to have begun meandering across its flood plain. Beautiful oxbow curves are frequent, and a sluggish nature is everywhere manifest during times of low water. The lesser tributaries usually have deep, narrow valleys, except near where they break through the bluff lines into the Cimarron. Here they often widen into surprising forms, and generally have their flood plains strewn with residual sands retained from the Tertiary beds of sand and clay.

CROOKED CREEK VALLEY AND FAULT.

Crooked Creek, the third largest stream in this area, has some anomalous features which make it interesting. It rises in the eastern part of Haskell County and flows almost due east to near the little village of Wilburn. Here it suddenly turns to the southwest, making an angle of about 60° with itself, to about 20 miles south of Meade, where it bears southeastward to its junction with the Cimarron River. The sharp angle in its course at Wilburn and its southwestern course between Wilburn and Meade, across a country with a maximum inclination to the southeast, are anomalous for a stream in southwestern Kansas. The area in the southeastern part of Meade County is gashed here and there with lesser drainage channels, all of which drain to the southeast in lines approximately parallel with the lower part of Crooked Creek. Some of these lesser channels rise almost on the eastern bank of Crooked Creek, leaving an unaltered table-land along the eastern bank of the creek, often little more than a mile in width, as is well shown on the Meade topographic sheet.

These peculiar physiographic conditions in the vicinity of Crooked Creek, in connection with geological data gathered from wells, led the writer to conclude that local deformation had produced them, and a preliminary notice of the same was published,[1] from which the following extracts may be taken:

> The bluff lines along Crooked Creek are quite interesting in character, particularly below Meade. Throughout the portion of its course where it flows east the bluffs on either side of the creek are not especially different from the ordinary. Tributaries from the north are most numerous, but quite a number are found entering the creek from the south in the northwestern part of Meade County. Farther east, opposite the artesian area, no tributaries of any consequence are found on the south, while arroyos of greater or less size are found every mile or two on the north. For 20 miles below the sharp angle at Wilburn scarcely a tributary as much as 2 miles in length enters from the east, while below Meade the drainage streams flowing southeast to the Cimarron rise almost on the verge of the eastern bluffs of Crooked Creek. Throughout this distance many tributaries

[1] Am. Jour. Sci., 4th series, Vol. II, 1896, p. 368.

enter from the west, the most important being Spring Creek, about 12 miles long, and Stump Arroyo, nearly as long.

The general character of the uplands is that of a broad plain inclined to the southeast about 10 feet to the mile. The various drainage channels are cut down into this plain, generally producing abrupt bluffs on each side. From Wilburn to Meade, however, the bluffs of Crooked Creek are far apart, with the whole of the artesian area between. Below Meade the bluffs on the east side of the creek are high and abrupt, often being almost precipitous in character. They have a decidedly new appearance, as though the erosion which produced them was very modern. Almost none of the rounded forms of old age are to be found, but the angular points and steep walls of recent formation are everywhere present. On the western side there is a gently sloping plain stretching from the creek to from 1 to 5 miles away, producing an appearance scarcely duplicated within the State. The general upland plain from 8 to 12 miles to the west of Crooked Creek both physiographically and geologically corresponds with the plain on the east of the creek, which approaches to within less than a quarter of a mile of the creek valley. The general appearance from Meade southward is that of a fault, with the western wall dropped and Crooked Creek occupying a position over the fault line. Northward the whole artesian valley seems to have been dropped downward, leaving an abrupt wall on the west and a more gentle wall on the east. Standing anywhere in the valley, one can see the wall all around. On the west it is considerably over 100 feet in height, while to the east it is somewhat less, but still very perceptible. We have here a valley occupying about 60 square miles which is so different from anything else known in this part of the country that it is exceedingly difficult to explain its origin by attributing it to erosion. The peculiar position of the creek is likewise hard to explain by ordinary erosion. The sharp angle at Wilburn and the southwestern direction for nearly 20 miles across a plain sloping to the southeast are certainly very remarkable, and probably have a cause different from that which ordinarily determines the location and direction of streams. But if in post-Tertiary times a triangular area equaling in size and position the present artesian area could have dropped 100 feet or more, with a single fault line extending southward to beyond the limits of Kansas, thereby changing the direction of Crooked Creek into the present channel below Wilburn, the general physiographic conditions could easily be accounted for.

It should be added that there is a chain of wet-weather lakes reaching eastward from Wilburn to the north of Minneola which may represent the former channel of the eastward extension of Crooked Creek. An examination of the country lends more color to this view than can be gained from the United States topographic sheets, for 20-foot contour lines often fail to represent physiographic conditions of great importance in such studies as these.

Along the upper part of Crooked Creek, from a few miles above Wilburn, the general conditions are those of a stream that has not yet reached base-level. In the artesian area and at all points below, the creek has a valley of considerable width and the general appearance of a stream which has long ago reached its base-level. The numerous ox-bow curves, due to the migration of the channel, are everywhere present. In addition to this, it is generally found that it has built up its banks until they are higher than the adjacent valleys. This is true to a perceptible degree almost entirely through the artesian valley, and is also true, but to a less extent, in the valley below Meade.

The general uplands of the area under consideration have the appearance of a broad peneplain which has been so elevated that a new set of flood plains is now being produced along the various channels. In

the western part the inclination of the surface is uniform and gentle, and but few channels of any description are found. The rapid inclination of the surface to the southeast throughout nearly all Meade County and the southern part of Seward County gives so great a fall to the streams that their erosive action is more pronounced, and consequently the surface has been changed to greater depth and a corresponding rugged topography produced. The rainfall is so meager that few of the streams have water in them as much as a quarter of the year. Those which have worn their channels deep enough to come into contact with the general underflow water have springs and seeps in great abundance along them, and pools of living water throughout the entire year. This wearing down probably has occurred, however, since the main part of the erosion was done, and consequently has exerted but a limited influence on the general physiographic features.

SAND DUNES.

One of the interesting topographic features frequently observed is that produced by the sand hills or sand dunes. On the south side of the Arkansas, throughout its entire length in this area, a strip of country varying from 4 to as much as 15 or 18 miles in width is covered by loose sand which has been blown by the winds into the hills and hummocks so common in sandy countries. The area is exceedingly irregular in its southern boundary. In some places it is not more than 3 or 4 miles across, while in others the distance is much greater. Near the western side of the Garden quadrangle the sand hills reach southward from the river almost uninterruptedly to within Haskell County, a distance of from 18 to 20 miles. Immediately south of Garden the sand hills extend only about 7 or 8 miles, where a strip of country is reached on which there is but little sand. But farther east, through the eastern tier of townships in Haskell County and Finney County, another southern projection of the sand hills area reaches from 12 to 15 miles south of the river. Still farther east, in Gray County, south of Ingalls and Cimarron, the sands likewise extend from 12 to 18 miles south of the river, or to within 5 or 6 miles of Montezuma. East of this area again, throughout the remainder of the Dodge quadrangle, the sand hills area gradually contracts in width, so that immediately south of Dodge it is only 4 or 5 miles in width. The extent and location of the sand hills are well represented on the topographic sheets of the United States Geological Survey.

In most places, both north and south of the river, outside of the area of river sand hills, relatively little sand is found on the uplands. In the vicinity of Wilburn and Fowler, however, east of Crooked Creek, an area of sand hills exists, covering 50 square miles or more, which has a general appearance similar to that of the river sand hills area. The character of the sand is practically the same, and in most respects the conditions south of the Arkansas River are duplicated.

Again, in the southeast part of Meade County, in the broad Cimarron Valley to the north of Englewood, an area of from 12 to 18 miles in width is covered with sand dunes which are practically the same as those on the south side of the Arkansas. The whole face of the country here for many miles up and down the Cimarron River, except some irregularly shaped areas, is covered with the sand. The exceptions referred to are peculiar and interesting. The greater part of the valley occupied by Colonel Perry's ranch has but few sand hills. Here we have an area 4 or 5 miles across, lying between the sand hills proper and the Cimarron River, the general character of whose soil is that of the alluvial soil common to the flood plains of rivers. Farther down the river to the east the sand hills approach almost to the river bank.

To the north of Englewood, where the sand hills are best developed, a portion of which territory lies within the Meade quadrangle, the sand practically covers the whole face of the country. It is blown into hills and valleys, irregular in outline and position, with no apparent indication of the directions from which the principal winds came. Here and there the sand is still blowing, producing barefaced hills with no vegetable covering, showing that the movement is still in progress. The greater part of the surface, however, is well covered with vegetation, which implies a cessation of the sand movement. The principal sand dunes seem to be residual in character—masses of sand left behind after the finer parts have been carried away by wind and water. For a fuller treatment of this subject the reader is referred to a discussion of the Physical Properties of the Tertiary, by the writer, in Volume II, University Geological Survey of Kansas.

PECULIAR ARROYO EROSION.

A peculiar form of valley erosion is noticed throughout western Kansas, a form thus far unobserved elsewhere by the writer, and one upon which no literature seems to exist. The lesser tributaries to the principal drainage channels in their uppermost course frequently are quite void of water almost the entire year. As a result of this, buffalo grass or blue stem entirely covers the bottom of the arroyos. Such arroyos usually are from 50 to 200 feet in width, even to their very sources. The peculiar and characteristic feature of such arroyos is the shape of the bank at the margins. In almost all instances over the whole western part of Kansas such arroyos have a vertical wall at the outside part of the bank, varying in height from 2 to 3 feet to a minimum of only a few inches. The whole bottom of the arroyo is, as a rule, covered with grass, and seems to have no corrasion marks along it. But on the outer borders the arroyo is separated from the main upland plain by the vertical wall. This feature is sometimes noted to a limited extent along the little sink holes which are so abundant in this part of the country. Some of these depressions,

measuring no more than 10 or 15 feet across, have the buffalo grass growing all over them, and have their walls assuming this vertical character, in every respect similar to the walls of the arroyos.

These interesting features of the physiography of the Tertiary plains seem to have been caused by the underground creeping of the looser sands and clay which are not held together by the grass roots of the sod. As water is so rare in the arroyos, the conditions are as favorable for the growth of vegetation in the bottom of the arroyos themselves as on the uplands. When the rains come, the ground is softened probably more in the arroyos than elsewhere, and is thereby made more easily movable. The existence of the water is of so short a duration that the mechanical action of its flow is not sufficient to corrade the surface. But as the inclination is generally quite steep, and as the water softens the clays and sands, gravity will cause a slow, but constant creeping downstream of the material which is not held in place by the grass roots. In this way the effect is similar to that which would be produced were a blanket spread from bank to bank of the arroyo, a blanket which was not removed or carried away by the drainage, but which would allow the grounds beneath to become softened and creep downstream by the influence of gravity. The blanket in question would move vertically downward as the material beneath it was carried away, and the vertical walls at the outside of the blanket would be maintained, constantly growing higher as the materials from beneath were removed by the downward creeping.

GEOLOGY OF THE AREA.

The general geology of this part of the State is now fairly well known. Excepting a few small portions in the southeast, the whole area is covered with Tertiary sands, gravels, and clays. The lowermost formation is the Red Beds, which are exposed along a few of the bluff lines and in some of the lowest valleys in the extreme southeastern part of the Meade quadrangle. Farther to the east, in Clark County and beyond, the Comanche overlies the Red Beds. This formation thins westward, however, so that only a few feet of the black Comanche shales is found anywhere within the Meade quadrangle, and that in the extreme eastern part. It seems entirely to disappear westward, as no traces of it have been found. Above the Comanche lies the Dakota, a formation consisting largely of sandstone. It is not exposed at the surface anywhere within this area, but has been reached frequently by wells, and is known to exist both to the east and to the west, so we are sure it is spread over the whole of the northern and central parts. The Dakota is followed by the Benton, which is largely a limestone formation consisting of beds of limestone alternating with black shale. It is found exposed at the surface in a few of the arroyos of Crooked Creek and along the Saw-

log in the northeastern part of the Dodge quadrangle, and it probably underlies the northern part of the Meade quadrangle. Covering the whole of these is the thin mantle of the Tertiary sands and gravels.

RED BEDS.

The Red Beds cover wide areas in south-central Kansas. They occupy the surface over the greater part of Clark, Comanche, and other counties to the east as far as Sumner County. They extend westward into Meade County, and are found at or near the surface over five or six townships in the extreme southeast corner of the Meade quadrangle. The broad valley around Englewood, which reaches northwest almost to Cash City, has the Red Beds for its floor. The Tertiary sands and gravels are irregularly scattered over this valley, in some places as much as 50 or 100 feet thick, while elsewhere the Red Beds are exposed on the surface. They constitute the main mass of the hills and bluffs to the west and northwest of Englewood, but on account of the Tertiary capping of the hills and the Tertiary sands and gravels in the valley below, when represented on the map they appear as narrow strips winding back and forth through the course of the various lesser tributaries, unless, indeed, the thin covering of the Tertiary in the valley should be neglected, and the whole represented as the Red Beds. They are exposed in the bluffs on both sides of the Cimarron at Englewood and on both sides of Crooked Creek as far up as Odee post-office, the farthest northwest exposure known covering a small area on the east bank of Crooked Creek about 3 miles above Odee.

The character of the upper surface of the Red Beds is interesting on account of the great irregularities which it presents. An examination of section 1 of Pl. IV will show that the surface of the country drops rapidly southward from near Minneola, and that the surface of the Red Beds likewise drops, inasmuch as it is about parallel to the general surface of the country. Aside from this rapid inclination southward there are other local irregularities. In the Cimarron Valley, where the whole surface is covered by a layer of the soil and silt from 10 to 15 feet deep on an average, occasional places have been found in well drilling where great depressions exist. At one farmhouse, on the land of Colonel Perry, a well was sunk to the unusual depth of 175 feet without reaching the Red Beds, while less than a half mile away they are exposed almost at the surface. Such irregularities are probably due to surface erosion in pre-Tertiary time.

Another irregularity is present which is probably of a different kind. As just stated, the Red Beds constitute the main part of the bluffs on the eastern bank of Crooked Creek from Odee to its junction with the Cimarron, and on the left bank of the Cimarron a few miles below. On the west bank of Crooked Creek the Red Beds are not found. Neither are they found on the south side of the Cimarron until a point is reached near the mouth of Crooked Creek, or almost in line with

the trend of the lower part of Crooked Creek, when suddenly they appear on the south side of the Cimarron in forms as massive and prominent as those on the north. This remarkable condition of the location of the Red Beds along Crooked Creek has already been referred to in these pages, and has been explained by assuming a fault line to exist along Crooked Creek, with the strata on the western side dropped to an unknown distance, at least 100 or 150 feet.

In constitution the Red Beds differ from anything else known in Kansas in a few important respects. Their bright color is their most striking characteristic. Wherever they are found they are readily recognized by this feature. No samples of them have yet been analyzed to determine their chemical composition, but it is evident that their brilliant color is due to the presence of large quantities of red oxide of iron intimately intermixed through the whole mass. They vary considerably from place to place, but seem to be composed entirely of clay and sand, very imperfectly bedded, but always colored with red iron oxide. In places far to the east we find beds of sandstone sufficiently cemented to form a low-grade building stone. Elsewhere the sands are entirely wanting. Many samples of the red clay have been examined which apparently contained not even traces of the fine sand.

Gypsum is another constituent, which assumes great prominence in the vicinity of Medicine Lodge and farther to the west. It seems to be well stratified in the vicinity of Medicine Lodge, forming heavy layers from 5 to 10 feet in thickness. These strata have a lateral extent of many miles, and have been important agents in the production of the peculiar and varied physiography for which portions of Barber and Comanche counties are noted. Gypsum has also been formed in many fissures, large or small, which cut the Red Beds in various places. These forms of gypsum are secondary in origin, and seem to have been deposited by infiltrating water probably long after the Red Beds themselves were lifted into dry land.

Salt is likewise scattered irregularly through the Red Beds. It is leached out by the water and is deposited along the salt marshes so common in the Cimarron River Valley to the south of the State line. Probably the salt is irregularly disseminated throughout the material; possibly heavy deposits of rock salt may yet be found beneath the surface, although no positive indication of such has yet been observed. It is certain, however, that in some way, while the Red Beds were forming, conditions were favorable for the accumulation of salt to so great an extent that in the aggregate the amount deposited is very considerable.

Thus far no fossils of any kind have been found anywhere in the Red Beds within this State. Those of Texas have yielded fossils of Permian character, and it is probable that they are of the same age as those of Kansas, although they have not yet been positively shown

VIEW OF RED BEDS BLUFFS, CAPPED WITH TERTIARY, ON JOHNSON'S CREEK, NEAR CAIN, MEADE COUNTY, KANSAS.

be connected. Little true stratification can be noted in the Red ds in places where their principal component is clay, but when nd becomes more abundant, so as to form a sandstone, the bedding anes are more strongly marked. In the southeastern part of the eade quadrangle, immediately at the summit of the Red Beds, is a lerably well defined sandstone from 3 to 6 feet in thickness, called e Basin sandstone, on account of its being so prominent in the walls ound the great basin in Clark County. At the southwesternmost posure of the Red Beds at Odee this sandstone seems to be wanting, hile the clay composing them is so entirely free from sand that no it can be detected by the teeth.

This absence of local stratification is almost lost sight of when we ntemplate the Red Beds as covering wide areas. They form a arked horizon between the Comanche or Dakota above and the lack shales and buff limestone of the Permian below. Through all estern Kansas they incline to the east or northeast or southeast, s is well shown by noting on the map their elevations at different laces where found. Where exposed at Odee they have an elevation f nearly 2,400 feet, while in the bluffs near Englewood, in places here we know the measurements are made on the uneroded upper urface, their elevation is but little more than 2,100 feet, making a ip of the upper surface to the east of fully 250 feet in a distance of 5 miles, or an average of near 17 feet to the mile. The same Red Beds were reached in a deep well at Santa Fe years ago at an elevaion considerably greater than where they are exposed at Odee, showng that as they extend westward their upper surface rises.

The origin of the Red Beds is pretty well indicated by their chareter. The large amount of iron oxide, of gypsum, and of salt which hey contain, and the total absence of fossils, imply that they are the esult of the accumulation of sediment in a concentrated ocean water. Many characteristics of the formations in central Kansas in the Upper Permian point to the existence of an inland ocean which was evapoating more rapidly than it was filling from surface drainage, thus roducing a stronger and stronger brine. The large deposits of rock alt in what has heretofore been called the Upper Permian—the salt eds supplying the mines at Hutchinson, Lyons, and other places in ie south-central part of Kansas—have probably been formed by the esiccation of an inland ocean. The dark-colored shale which is nbedded with the salt in these places likewise implies that sufficient rganic matter, either from sea or land, was accumulated with the arthy masses which constitute the shale to give them their black olor. As time passed the accumulation of organic matter from all ources was finally prevented. As a result, the surface oxidation of ie iron compounds leached from the adjacent land was carried on to n extent sufficient to produce the red color in the sands and clays of ie Red Beds.

An important lesson may be gathered from these considerations by one studying the water problem in western Kansas. Should a well penetrate the Red Beds, their fine-grained, compact, argillaceous character makes it extremely doubtful whether water in any considerable quantity can be obtained from them; and still worse, should water be obtained it is almost certain to be so mineralized with salt and gypsum and other soluble products that it will be entirely unsuited for either domestic purposes or for irrigation. Therefore, should anyone when using the drill in the search for water anywhere in the southwestern part of the State penetrate the Red Beds, he should immediately discontinue boring, lest he spoil the character of the water he may have already obtained.

DAKOTA.

The Dakota formation underlies about three-fourths of the area covered by this report. Its position is well shown in the accompanying geologic sections (Pl. IV, p. 42). From these it will be seen that it gradually thickens to the north and thins southward until it entirely disappears. The southeastern limits of the Dakota can not be outlined in detail on account of the heavy mantle of Tertiary which conceals it from view in most places.

In character the Dakota is largely a sandstone formation, so much so, indeed, that it is frequently spoken of as the Dakota sandstone. Every deep well which has penetrated it in southwestern Kansas shows that shales are embedded with the sandstone. The extent of these shale deposits is not known, for nowhere can we find any exposure of the Dakota at the surface. Farther east, in other parts of Kansas where they come to the surface, it is seen that a considerable proportion of the thickness—probably more than half—is shale of some kind. In most places where exposed at the surface in Kansas the sandstone is colored brownish red by iron oxide, and in some places in this area the drill has brought up the same brownish-colored sand. Farther west in Kansas and Colorado the brown color is not so prominent.

The Dakota formation has an unusually great extension. It reaches from the Dakotas southward into Texas, and probably beyond; from central Kansas westward to the "Hogback," near the eastern foothills of the Rocky Mountains, and northwestward into Montana and Wyoming. As a sandstone it is characterized by great uniformity of texture and a small amount of cementing material to bind the grains together. The latter property makes it an open and porous rock, so that it can serve as a great underground reservoir capable of holding a high percentage of water or of allowing a relatively free transmission of water from one place to another within it. Westward from Kansas it is found sometimes at the surface, where it can absorb the *rainfall, sometimes* in contact with the Tertiary, so that the under-

ground water of that formation mingles with its own, and sometimes buried beneath the Benton and higher Cretaceous formations. It seems to have an unbroken continuity from its exposure in Kansas westward almost to the mountains, throughout which distance it has an average dip to the east of from 5 to 8 feet to the mile. It is, therefore, a most important formation to anyone studying the water problem in Kansas, and will be recalled for a further discussion later in this report.

BENTON.

Above the Dakota lies the Benton, a formation composed of alternating beds of limestone and black or dark-colored shale. The proportion of shale to limestone is probably about as 1 to 4 or 5. The limestone is generally a light buff in color, sometimes inclined to a bluish hue on unweathered surfaces. It is usually much softer than ordinary limestone, but fragments exposed at the surface show perceptible hardening. It always contains large quantities of fossil shells.

The Benton formation is exposed at the surface in the northeastern part of the Dodge quadrangle along Sawlog Creek and some of its deeper tributaries. It is again exposed over small areas in places along the northern tributaries of Crooked Creek in the southern part of Gray County. Aside from these two limited areas it is entirely concealed from view by the overlying Tertiary sands and clays. However, we know from the records of different wells and from its occurrence elsewhere that it underlies the Tertiary formations over the whole of the northern part of this area, reaching southward to the banks of Crooked Creek, and probably farther on the western side.

Many wells reached it at different places in township 29, in the southern part of Gray and Ford counties, some of which penetrated it 150 feet and more without passing through it, while others, farther east and south, proved that its thickness there was much less. The city well at Santa Fe is reported to have found but 13 feet of the Benton limestone. It would seem, therefore, that there is a considerable thickening east from Santa Fe, as shown in the geologic section.

Farther west, in the vicinity of Hartland, Kendall, Syracuse, and Coolidge, the Benton is exposed in the bluffs along the north bank of the Arkansas River, furnishing a limestone which is quarried at different places. There is little room to doubt, therefore, that the Benton underlies the whole of the area north from the southern limits along Crooked Creek to Santa Fe, as already described.

Neither the Benton limestones nor shales are water bearing. Not a single well has yet been drilled in the shales which found water in them. The limestone is a fine-grained mass, capable of holding or transmitting but little water, while the shales are so close and compact that they are entirely incapable of permitting any considerable quantity of water to pass through them. The Benton, therefore,

furnishes a floor impervious to the water of the overlying Tertiary sands, a floor preventing the Tertiary ground water from passing downward and the water of the Dakota sandstone from passing upward.

TERTIARY.

The Tertiary formations in Kansas are composed principally of gravel, sand, black sand, clay, and silt, with a small amount of material usually called "volcanic ash." These materials are mixed together in an irregular manner, so that the same relation does not exist between them in different localities. The gravel consists of pebbles varying in size from 4 or 5 inches in diameter to the finest, grading into sand. They are composed principally of the ordinary rock-forming minerals, and seem to be fragments of granite, syenite, porphyry, andesite, rhyolite, basalt, and not infrequently of pure quartz. Their character leaves little room for doubt that they were carried here from the mountains to the west.

The relative position of the gravel beds is variable. In some places they seem to be near the bottom of the Tertiary; elsewhere they are on the summit of the highest hills. A good example of the latter is found along Spring Creek, in Meade County, about 4 to 8 miles southwest of Meade Center. Here the so-called mortar beds—a mass of gravel and sand cemented with calcium carbonate—cap the top of the highest hills in the country. Some of them have the butte form so common where hills of erosion have a hard covering rock on top of a larger mass of soft material.

The sand is composed of sand grains ranging in size from the ordinary coarse sand which grades into gravel down to the finest of sand. The grains are principally of ordinary quartz, but are usually intimately associated with feldspar particles, confirming the teachings of the gravel regarding their origin. The sand is about as well stratified as the gravels already mentioned. In places beds of sand are found well stratified, while elsewhere it is so intimately mixed with clay or gravel that the formation can hardly be called sand beds.

Almost everywhere in the Tertiary are found small accumulations of black sand, which have been slightly segregated by rain water carrying away the finer materials and leaving these little grains behind. Originally they are intimately mixed with the clay and finer quartz sand. The little rivulets of water on the hillside carry away the lighter particles of clay and silt and let the black sand grains accumulate along the wagon tracks of the country roads and the eddies of the small ravines. These black grains are found to be composed entirely of black oxide of iron, principally magnetite, but partially dark hematite. Doubtless they were original constituents of the crystalline rocks of the mountains to the west. When the rocks were disintegrated by weathering and the débris was transported *eastward by water*, the iron oxide grains were carried along with the

TERTIARY BLUFF AND SPRING-FED POOL. DUCK CREEK, 5 MILES NORTH OF DODGE, KANSAS.

· material and lodged here and there wherever the current veloc-
permitted.
e clays and silts vary in character from place to place and at
ent depths. Occasionally almost pure masses of clay are found,
almost entirely free from admixtures of sand, clay with a high
e of plasticity and in every respect resembling the purest known,
pt that it contains sufficient impurities to modify its color. Fre-
tly such masses of clay seem to be colored with decaying organic
er, as though during its accumulation such matter in one form
other was present, at least in limited quantities. Elsewhere the
· of the clay seems to indicate the absence of organic matter of
kind.
e stratigraphic property of the clay is interesting. In places it
s in broad layers, apparently extending for miles in unbroken
. Elsewhere it forms lenticular masses, oblong in horizontal
nsions and irregular in peripheral outlines. Sometimes it is
bedded with the heavy gravel and sand beds, and elsewhere
s to be relatively distinct from them.
ong the Arkansas River Valley, near the bluffs north of Garden
, a heavy bed of clay nearly 100 feet thick extends up and down
alley for 4 or 5 miles. Its north-south diameter is usually about
a mile. South of the river 12 or 15 miles from Garden City is
her locality in which occur irregularly shaped clay beds or clay
ders, as they are locally called. During August, 1896, a well was
d about three-fourths of a mile south of Atwater, in Meade
ty. It went to the surprising depth of 288 feet, passing through
ing but a light-blue plastic clay almost the entire depth. Other
on every side of this one, from 1 to 2 miles away, found the
l amount of water-bearing sand at from 20 to 40 feet. Such illus-
ons could be multiplied until the whole of the Tertiary of Kansas
overed. Everywhere such irregularities exist. Few wells have
made which did not pass through both sand and clay. Even in
and hills south of the Arkansas River the few wells dug or bored
riably found clay. The State well in the sand hills just south of
rron may be taken as an example. At a depth of 23½ feet a bed
markably compact plastic clay was reached, about 5 feet in
ness.
many places in western Kansas and elsewhere on the plains a
l amount of a fine-grained matter is found, which is generally
d volcanic ash. A few deposits of the same material have been
d in this territory. The best exposure known is along a tribu-
to Crooked Creek, about three-fourths of a mile west of Meade
er, although other lesser deposits are known in Meade County
elsewhere.
er a large portion of the whole Tertiary area of the plains the sur-
is covered with a fine-grained soil which has so high a percentage

of clay within it that it has a relative high plasticity and other properties that have given it the name "Plains marl." It covers more than half of the surface, but by no means all of it. Neither is it confined to the surface, for often the same kind of material is found interbedded between layers of other materials. It is probably composed of the finest silt and clay particles which migrated eastward during Tertiary time and were lodged here and there wherever the conditions of water velocity dictated. In recent times, also, the winds have exerted a sorting action on the surface materials, which has helped to make the Plains marl more characteristic. The strong winds pick up the finest dust and carry it for miles and deposit it wherever a suitable lodging can be secured. This not only concentrates the finest materials together by movement, but also leaves the coarser soils and sands behind, so that the same process produces sand dunes and sandy soils which are often mere residual products after the finer silt has been blown away.

The structural relations of the different Tertiary materials are far from regular. It is doubtful if there can be any definite stratigraphic relations established covering a considerable scope of country. The gravel and sand are frequently cemented into a moderately firm rock by the presence of a variable amount of a calcium carbonate cement. This cement is sometimes found in the clay as well, but it is most abundant in the sand and gravel, producing a sort of sandstone or conglomerate to which the name "mortar beds" or "grit" is generally applied. Some of the varieties of this are the so-called "natural mortar," which is extensively used throughout the West for making a mortar to plaster with and to roof houses. These mortar-bed horizons are prominent features in many places and constitute the only hard and resisting strata in the Tertiary. The idea so frequently expressed, that they are located near the base of the Tertiary, is correct for some localities, but incorrect for others.

Along the Buckner, in the southwestern part of Hodgeman County, the sand and gravel are as firmly cemented as at any place known to the writer. Here they form a tolerably solid rock which lies at the top of the bluffs on the south side of the Buckner. They are in beds from 10 to 20 feet thick, varying much more than ordinary sandstone beds do. Below them in this locality the bluffs are composed of a looser and finer material. At other places along the Sawlog, near by, the mortar beds are found near the bottom of the Tertiary, and not infrequently resting immediately upon the Benton limestone.

The north bluff line of the Arkansas River from some distance below Dodge westward almost to Garden is protected by a well-developed mass of mortar beds. Throughout the most of this distance three distinct layers of mortar beds can be traced, while in other places four or more may be found. They are composed of cemented sand and coarse gravel, and are separated from each other by beds *of clay and fine* sand. The weathering processes wear away the soft

clay beds more rapidly than the mortar beds, producing a series of narrow terraces along the bluffs similar to those generally observed in places where the limestones and shales alternate with each other, as so frequently occurs in the eastern part of the State.

South of the Arkansas River but little of the mortar-bed material is to be seen until the vicinity of Crooked Creek and the Cimarron is reached. Here we have the same lack of regularity so noticeable elsewhere. The most pronounced form of the mortar beds is often found at the very summit of the bluffs, but by no means always so. In other places they occur midway up the bluff, and not infrequently near the base. The bluffs of Crooked Creek below Meade are good examples of this. On the eastern side of the creek they are very rugged, with frequent instances of mortar beds being well developed, but by no means do they form a constant stratum continuously along the bluff. On the western side the bluff line is not so abrupt, and consequently there is not so good an opportunity for observing the mortar-bed masses. To the southwest of Meade, along the upper portion of Spring Creek, however, some of the hilltops are very distinct, and the erosive forms are significant of hills with a protecting cap of hard material covering softer materials. These can well be studied from the Meade topographic sheet. A few of these hills are particularly noteworthy. On the north bluff of Spring Creek, about 4 miles above Crooked Creek Valley, the mortar beds are found lying at the summit of the hill. The sandy clay underneath is worn away, so that quite frequently the mortar-bed rock projects several feet, forming an overhanging cliff. South of Spring Creek a similar condition obtains. Hill point after hill point stands out in the landscape as a prominent feature, on the top of which a horizontal mass of mortar-bed rock serves as a protection to the soft and easily eroded sandy clays beneath.

Along the Cimarron River from some distance above Arkalon to where the river encounters the Red Beds near Englewood its valley is cut downward into the broad plain to a depth of nearly 200 feet. As one stands on a prominent point on either side of the valley and looks up and down the stream, it is easy to see the line of light-colored mortar beds lying almost at the summit of the bluffs, with the darker colored shales and sands beneath. A more careful examination shows that for many miles along the stream relatively firm rock covers the topmost part of the bluffs, and it is largely to this that the precipitous character so pronounced on either side of the river around Arkalon is due. Beneath the mortar beds are found masses of sandy clay, which constitutes the main mass of the bluffs. At other places, particularly along some of the tributaries of Spring Creek near Meade Center, the mortar beds in a well-developed form are found on low ground more than 100 feet below those capping the hills a mile or so away, with no connection between them.

During the *last two years* the Kansas State Board of Irrigation has

sunk twenty wells in western Kansas, the greater portion of which are confined to the Tertiary. One of the provisions in the contract for the drilling of each well was that a carefully selected and accurately labeled suite of samples should be preserved and delivered to the board, such samples to be taken with sufficient frequency to accurately represent the character of the material passed through. These samples from the different wells were turned over to the writer by the Board of Irrigation and have been carefully examined. This is the first time it has been possible to examine the Tertiary materials at any considerable depth below the surface, except where they are found along the bluff lines of the various drainage streams. They are therefore of more than ordinary importance, and are worthy of notice in this connection.

It was found that little relation existed between the distance from the surface and the size of the gravel. Gravel beds of a considerable degree of coarseness were frequently found near the surface, and the finest sand and clay and silt were not infrequently found near the base of the Tertiary. There was such an irregularity of position shown with reference to any one material, and such a lack of definite relation between the different kinds of material, that it seemed as though but little if any dependence could be placed in any older classification.

In studying the physical properties of the Tertiary it is necessary to emphasize the statement that the so-called mortar beds are simply the sand and gravel and clay materials cemented usually with calcareous cement. The real stratigraphic conditions probably do not depend upon the presence or absence of cementing material, but rather upon the continuity of beds of like material. A stratum of gravel which is not cemented should be considered as important as though it had chanced to have its individual constituents held together by a cementing material of some kind. Yet in our study of the subject we are usually inclined to erroneously regard the beds which are cemented into a firm rock as more important than softer materials. It has been suggested by the writer that the formation of the cementing material has occurred since the deposition of the beds, and that it represents a process of weathering and desiccation still in progress. The ordinary weathering agents produce calcium carbonate near the surface, which is changed to the acid carbonate by rain water containing carbon dioxide washed from the atmosphere. It is then dissolved and carried downward until the dryness of the ground absorbs the moisture, precipitating thereby the neutral carbonate in whatever position it chances to be. As the beds of gravel and coarse sand more freely permit the passage of water through them than do other materials, naturally there would be a greater deposition of calcium carbonate in such beds.

It is doubtful if there can be any regularity discovered between the *beds of* the different kinds of Tertiary material in western Kansas. *The mortar beds* occur at all positions from the base to the summit,

as do also the sands and the clays. It has been found impossible to trace a bed of any one material very far in any direction. The records of the State wells add to this difficulty rather than lessen it. Neither does the assistance of paleontology lessen the difficulty, but rather increases it. In Phillips County the mortar beds contain skeletons of the rhinoceros and other animals, indicating that they should be correlated with the Loup Fork beds of Nebraska, and that they are about the oldest Tertiary beds in Kansas. To the southwest, in Meade County, a mass of conglomerate, which is as typical a mortar bed as can be found, is rich in fossil horses, llamas, elephants, etc., which paleontologists class as Pleistocene fossils. We therefore have the mortar beds with Loup Fork fossils at one place and with Pleistocene fossils in another, not only showing a lack of stratigraphic continuity, but showing that, after all, the so-called Tertiary of the State may be part Tertiary and part Pleistocene.

WATER SUPPLY OF THE AREA.

In the discussion of waters on the Great Plains it is well to bear in mind the different conditions under which water exists and the different classes into which the ground waters may be divided with reference to the geologic character of the materials in which they are found. Geologically we have two great classes of ground waters. One exists in the Dakota sandstones. It probably has a slow movement eastward, has principally been gathered from the rains falling in the eastern part of Colorado and farther to the north over areas where the sandstone is exposed at the surface, and in its eastward movement passes underneath the Benton, Niobrara, and other superior Cretaceous formations, so that in most places it exists under a pressure sufficient to cause it to rise an appreciable distance above the level at which it is found by the drill, giving artesian wells, or wells decidedly artesian in character.

The other water is that which is commonly known as ground water, sheet water, or underflow, as these expressions are understood by the people of western Kansas. It is confined to the Tertiary sands and gravels. It lies immediately above the impervious Cretaceous or Red Bed floor, and is sufficient in quantity to more than saturate the materials in which it exists for a distance above the floor varying from 5 to more than 100 feet. Throughout the greater part of the plains area, therefore, these two classes of water are separated from each other by all of the Benton and higher Cretaceous deposits. In rare cases, however, the Tertiary rests immediately on the Dakota sands, permitting the Tertiary water and the Dakota water to commingle. Could we exhaust the supply of either one to an appreciable degree, the other would doubtless be drawn upon and a movement would be set up from one into the other. Still, for convenience of discussion and clear presentation of the water conditions, it is desirable that the two classes *should be discussed* separately.

DAKOTA SANDSTONE WATER.

The Dakota formation consists largely of beds of sandstone the grains of which are generally but poorly cemented together, leaving spaces between them which may well serve as receptacles for water. This sandstone, as before stated, underlies the greater part of the plains area from the British possessions on the north to Texas on the south. Throughout this entire distance it extends westward to the mountainous area, lapping upon the foothills along the eastern slope of the Rocky Mountains or capping the ridge generally known as the "Hogback," lying just east of the mountains in Colorado, as has been so well shown by Gilbert in his recent article on water conditions in eastern Colorado.[1] In this vast area are many localities where the Dakota is exposed to the surface, so that it can gather water from the rains and melting snows and occasionally from rivers which pass over it. The water which is absorbed passes eastward or southeastward or northeastward, the direction depending upon the inclination of its strata in different localities.

This great geologic formation is a continuous underground sheet for thousands of miles in extent, and has been imbibing water from the rains and snows perhaps for thousands of centuries. It has thus become a great reservoir filled with water, the leaks from which are known in the form of springs and seeps along its eastern borders in many places where it is brought to the surface, and also along the banks of streams which have cut their channels downward until the Dakota has been reached.

In a general way it may safely be said that all that is necessary to obtain water on the Great Plains is to penetrate to the Dakota sandstone. This proposition, although true in a general way, may not be verified in every instance. It is reasonable to suppose that a rock mass covering so wide an area is not perfectly uniform throughout. Here and there may be areas where the cementing material is more abundant than ordinary, or where the grains of sand are finer, or where the sand beds in their original form had silt and clay intermingled to a sufficient extent to produce a relatively impervious mass. We know, in part, that such conditions obtain at irregular intervals, and that consequently a drill hole made in such a place will yield but little if any water; not because the great Dakota beds were not reached, but because they were reached at a place where the open spaces between the sand grains had been filled with clay or mud or cementing material so that water could scarcely flow through.

Experience in drilling for water in the Dakotas, in Nebraska, in Colorado, and in Kansas abundantly verifies the statement just made, that in a general way one may confidently expect to obtain water in large supplies wherever the drill penetrates the Dakota sandstone.

[1] *The underground water of the Arkansas Valley in eastern Colorado*, by Grove Karl Gilbert: *Seventeenth Ann. Rept. U. S. Geol. Survey*, Part II, 1896, p. 582.

CHARACTER AND OCCURRENCE OF DAKOTA WATER.

The character of the water obtained from the Dakota sandstone is variable. Underground water is pure or is mineralized, according to its opportunities for dissolving soluble mineral salts. Could water be confined continuously in a perfectly pure mass of sand or sandstone which had no soluble materials within it, and into which no soluble salts could be taken by infiltrating waters, its character would always remain pure. But nature rarely accumulates a mass of sand without having at least traces of soluble materials along with it. Few terranes are known anywhere in the world which can permit waters to percolate through them for hundreds of miles without giving up mineral matter to the water somewhere throughout the course. It is so with the Dakota sandstone, yet not universally so. For some reason which has not been determined, water which is lifted from the Dakota at one place may have a greater or less amount of dissolved mineral salts than water obtained from the same sandstone 50 or 100 miles away.

The natural processes by which the impurities are gathered from the rocks by the water are such that it is exceedingly difficult for one to give an approximate statement regarding the character of the water that may be found at any locality, unless one can be guided by the water which has already been found near by. This, likewise, is substantiated by our limited experience in drawing water from the Dakota sandstone. The wells at Rocky Ford, La Junta, and other places in Colorado are all mineralized to a similar extent. The springs which burst forth from the banks of the creeks and rivers near by are likewise mineralized.

In Kansas the few wells which have been drilled in the Dakota sandstone have produced different degrees of mineralized water, differing materially in composition from one another and from many of the wells of Colorado and Dakota. The artesian water at Coolidge, which is a Dakota sandstone water, is relatively fresh, carrying little more than 24 grains of solution to the gallon. It has but little odor of hydrogen sulphide, and is in every way a desirable water for all domestic purposes. Farther north, in the vicinity of Oakley, a well reached the same horizon and likewise obtained water, but this was so heavily charged with common salt and other soluble minerals that it was practically worthless. An artesian well east of Oakley, in Saline County, drawing large quantities of water from the same Dakota sandstone, produces a water which is somewhat different from either of those, but which is so salty that it is of but little value for domestic purposes or for irrigation.

In the vicinity of Ness City, Larned, and other points near the Arkansas Valley, the few wells which have reached the Dakota have uniformly obtained water of a high degree of purity, well suited for domestic purposes. These examples are sufficient to show the varied character of the water obtained from the Dakota sandstone; in some

places the water is of good character, while in others it is highly mineralized.

Thus far but few wells in the special area discussed in this report have penetrated the Dakota sandstone. Not one is known to the writer to have done so north of the middle of the area, and but few to the south. In northeastern Meade County and the southern part of Ford County, four or five different wells are known to have passed through the Benton and reached the Dakota. In every instance the water obtained seems to be very abundant, rises to a height of from

FIG. 2.—Reservoir and windmill pumping water from Dakota sandstone, about 18 miles south of Dodge, Kansas.

50 to 150 feet above where it was first reached, and is of so high a degree of purity that no mineral properties whatever are noticeable to the taste. At Santa Fe, likewise, the city well passed through the Benton into the Dakota and obtained a good supply of water of as high a degree of purity as anyone could desire for domestic purposes. These Dakota waters have not been analyzed, largely because their purity is so apparent that analysis has seemed unnecessary.

By referring to the accompanying map (Pl. I) it will be noticed that the southern limit of the Dakota formation passes from a line near *Minneola, on the east,* to a point a few miles south of Santa Fe, on the

west. It may confidently be stated that the Dakota sandstone extends northward from this boundary under the whole of the area, and that it is water bearing throughout its whole extent. Therefore, a well put down to a depth sufficient to reach the Dakota sandstone will be supplied with abundance of water.

These predictions are based upon the well-known extension of the Dakota sandstone and its property as a water-bearing formation. The depth to which wells at different places will have to be carried to reach the waters of the Dakota sandstone can only be given approximately. By referring to the different geologic sections on Pl. IV it will be seen that the Dakota deposits to the north lie at a similar angle. Our knowledge of this subject is only fragmentary. A deep well at Garden is reported to have reached the Dakota at a depth of 461 feet. This information is all that was available from that part of the area, and section 3 was based upon it.

North of Dodge the Benton is exposed on the surface. Its thickness at this place is not known, but different wells have passed into it from 100 to 200 feet. Farther south, in southwestern Ford County, the Benton is known to be at least 150 feet thick, while farther to the northeast, where it is exposed at the surface, it is estimated to have a thickness of about 400 feet. From these data it was estimated that its thickness at the northeast corner of the Dodge quadrangle is about 400 feet, and section 1 was drawn accordingly.

The areas lying between sections 1 and 2 and 2 and 3 will have the Dakota at about the same distance from the surface. If, therefore, anyone should desire to estimate the depth he would have to go at any particular place to reach the Dakota sandstone, he could obtain an approximate idea by referring to these sections.

These representations here made should be regarded as only approximations, but the best that can be made with our present knowledge. Should a few wells be drilled north of the Arkansas deep enough to reach the Dakota sandstone, corrections could then be made which would make it possible to estimate the distance below the surface at which the Dakota would be reached over the whole area.

ARTESIAN PROPERTIES OF THE DAKOTA WATER.

The Dakota water in all places has artesian properties to a greater or less degree; that is, the water rises through a varying number of feet from the level at which it is found. At Coolidge different wells, when properly cased, gave a constant flow of from 40 to 50 gallons per minute from a 3-inch well. Farther east, at Syracuse, like wells have reached the Dakota and have produced water, but not one has yet been properly cased to determine whether or not the water would rise to the surface.

Northward, in the vicinity of Ness, where the surface elevation is slightly less than the uplands in the vicinity of Dodge, the waters

from the Dakota sandstone rise to within from 35 to 75 feet of the surface. It is probable that wells of this character could be sunk in the area under discussion in which the water would rise nearly to the surface, and possibly in some instances an artesian flow might be obtained. Yet one should not depend too much upon obtaining an actual flow, for it is doubtful if such would be obtained anywhere except in the lowest ground. There can be no good reason, however, for doubting that the water would rise to a point rarely more than 100 feet below the surface, and in many instances much higher than this.

The constant drainage along the eastern borders of the Dakota decreases the water pressure to so great an extent that the height to which it will rise is materially reduced in the Dakotas[1] and Minnesota. The decrease in pressure is frequently as great as 4 feet to the mile near the eastern border of Dakota, a decrease which is attributed largely to leakage. No observation has been made in Kansas to determine the rate of decrease in pressure. Such, in fact, could not be done to any satisfactory degree without a larger number of wells upon which observations could be made.

HOW TO FIND THE DAKOTA SANDSTONE.

Many inquiries have been made by citizens in various parts of Kansas regarding the means by which they could determine how to find the Dakota by boring. As already stated, the whole of the area covered by this report north of the south limit of the Dakota is underlain by the Dakota sandstone. When one drills a well expecting to reach this formation, the Tertiary sands, gravels, and clays will probably first be passed through, and whether or not the Tertiary water is found will depend upon a number of conditions which obtain in the vicinity of the well. Below the Tertiary, limestone and black or dark shale alternating will probably be found. The shale is the material commonly called "soapstone" by the most of the well drillers. In all such cases, as long as the drill is in the shale or limestone the driller should keep on going deeper. Finally the drill will pass through the Benton shales and limestones and enter the Dakota sandstones and clays.

If for any cause or combination of circumstances the desired supply of water is not obtained, he should go deeper, for the Dakota sandstone exists in two or more different layers, separated from each other by clay or shale of varied characters. The only condition which should cause him to stop drilling before the desired amount of water is obtained is that the drill has reached the Red Beds exposed on the surface in the southeast part of Meade County. We do not know how far north these Red Beds extend, but probably they reach far beyond the limits of the territory to which this report pertains. They can be

[1] *Preliminary report on artesian waters of a portion of the Dakotas*, by N. H. Darton: *Seventeenth Ann. Rept. U. S. Geol. Survey*, Part II, 1896, p. 666.

cognized when reached by the drill in a number of ways. They are nerally free from sand, but not always; they are usually slightly ty or in some other way mineralized, so that they may be recognized the taste; and they have mixed through them small masses of psum, a property rarely observed in the Dakota clays or shales ing between the Dakota sandstones. As soon as the driller becomes tisfied that his drill has entered the Red Beds, operations should be pped immediately. There is no evidence favoring a hope that the ed Beds will produce water in large quantities, while there are many asons for believing that the small amount which may be obtained om them will be so highly mineralized as to be entirely unfit for use any kind.

TERTIARY GROUND WATER.

Under this heading are placed the waters drawn from the Tertiary rmations. They include all water that may be found in Tertiary nds, gravels, and clays; that is, all available water lying above the ppermost Cretaceous formation. It is the water which is generally nown in the West by the terms "underflow" or "sheet water," names hich reflect the popular idea regarding the extent and character of ie ground water of the plains. The water is found in greatest undance just above the Red Beds or the Cretaceous floor. The wer portion of the Tertiary sand and gravel is more than saturated, id available water results. The thickness of the water-bearing beds variable, sometimes being more than 100 feet, and elsewhere being ss than 5, but always the water-bearing horizon rests on the impervi- us Cretaceous or Red Bed floor, or on a like impervious floor of clay. Almost all the area comprised in this report is underlain by large uantities of water. In the Arkansas Valley and the low grounds long other streams the water is usually found at depths varying from to 12 feet. On the higher uplands its distance below the surface is reater, in some places even reaching 200 feet, and possibly more. 'he water is everywhere present except in a few small areas, such as ie area in the northeast corner of the Dodge quadrangle, where the enton limestone is exposed at the surface, and similar areas in the outheast part of the Meade quadrangle, where the Red Beds come lose to the surface. Elsewhere, speaking in a general way, a well ut down at random on any quarter section will produce water if car- ed to a sufficient depth.

DEPTH OF TERTIARY GROUND WATER.

An attempt has been made to represent graphically the distance elow the surface at which water may be found for the whole area. xtensive examinations were made during the past summer, which cluded an investigation of almost every well outside the Arkansas alley. Mapping the location of the wells and noting the depth from hich water had to be pumped, it was possible to draw a series of

lines on the surface of the map which may be called the water contours. These lines divide the area into a number of little groups, so that those similarly marked have water at about the same depth, somewhat as the contour lines on an ordinary topographic map represent areas of equal altitude. The results obtained by this method of representation are shown on the accompanying map (Pl. V), on which the different areas represented by the same pattern have the water lying at about the same depth from the surface. It may be said that too much confidence should not be placed in this map. When the long distances between wells on the uplands are considered, and the relatively large proportion of the uplands over which wells have not been drilled, it will be seen that it is necessarily impossible to construct a map of this kind which will be entirely accurate. Yet it is believed that the one here presented has a fair degree of accuracy, and that confidence may be placed in it to a moderate extent.

By an examination of the map it will be seen that along the principal river valleys the water may be found at a depth of 50 feet or less. Over the whole Arkansas Valley, aggregating 200 square miles or more, the depth varies from 5 to 12 feet. Likewise in the Meade artesian valley, along Crooked Creek, the surface water rarely exceeds 12 or 15 feet in depth. The valley of the Cimarron to the southwest is another place, where water can generally be obtained at a depth of less than 20 feet. An area to the north and northwest of Dodge, along the Sawlog and Buckner, covering many square miles, likewise has the water less than 50 feet in depth, while still another area in the southeast corner of Meade County, an area equal to 75 square miles or more, has water, when found at all, generally at a depth of less than 50 feet. This area, however, is one of the most uncertain ones in the county. The Red Beds are near the surface, with an irregular covering of sand and gravel. Sometimes the well will pass into the Red Beds without obtaining water in any considerable quantity, while perhaps less than a mile away water is found in apparently inexhaustible supplies. This variation of conditions seems to be due to the irregularity of the surface of the Red Beds, a condition which can not be foretold and which can be determined only by the extended use of spade or drill.

The areas over which water may be found at depths varying from 50 to 100 feet are greater in the aggregate than those just given. Nearly the whole of the country lying to the north of the Arkansas River comes under this division, although the high bluff lines along the Arkansas are not included. South of the river a strip reaches from west of Garden eastward entirely to the east side of the Dodge quadrangle. There is another area of like depth through the high divide between the Arkansas and Crooked Creek, covering the main portions of the south part of Ford and Gray counties and reaching far into Meade County on each side of the artesian valley and along Crooked

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ek, with irregular areas in the east-central part of Meade County l lesser outlying areas elsewhere.

The next contour, with a depth varying from 100 to 150 feet, covers ike area and includes a portion of the high divide from Dodge westrd almost to Garden, a portion of the divide between the Arkan- River and Crooked Creek, and a large portion of the high uplands Meade County and a considerable part of Haskell and Finney nties. The area covered by the next contour interval, that of m 150 to 200 feet, covers nearly all the remaining territory. North the Arkansas River it is represented by a small, irregular strip near dge. Southward it covers the remainder of the high divide between e Arkansas River and Crooked Creek and a small portion of Meade unty to the southeast of Meade. It likewise occupies a large terory north of the Cimarron River, in the vicinity of West Plains and ringfield, reaching northward to beyond Santa Fe, thus occupying arly all the broad, apparently level plain from Santa Fe to Springld. The contour interval greater than 200 feet is represented in t few places in this area so far as we know. A few miles to the rth of West Plains wells were found which were more than 200 feet ep, likewise in the southwestern part of Seward County and in an ea northwest of Santa Fe. Could a larger number of wells be drilled er the high plains of Seward and Haskell counties, it is quite possie that this contour interval would be extended.

LEVEL OF TERTIARY GROUND WATER.

The water contours cross and recross the elevation contours in an egular manner. In one respect they are independent of the elevan contours, and yet over small areas they bear a close relation to em. Thus on a given farm a well in the valley will have to be nk a much less depth than on the uplands near by, and the differce in depth can usually be closely estimated by obtaining the difence in the surface elevation. For example, water in the Arkansas lley at Cimarron can be had at a depth of from 6 to 12 feet, while niles to the north, on the uplands, 140 feet higher, a well would obably have to be sunk 150 feet before water could be reached. e may cover much wider areas and still find the same condition aining in a general way. If a closer scrutiny of the conditions er wide areas be made, it is found that the upper surface of the ailable water is by no means on a level, but that it has marked riations of elevation which in a general way agree or correspond h the upper surface of the Cretaceous formations which lie buried neath the Tertiary sands.

These conditions are well illustrated by the six different geologic tions crossing the area to be described. By reference to them (Pl.) it will be seen that the water level in the various wells is almost lependent of the distance below the surface of the ground, but that

it is largely dependent upon the distance above the impervious floor. In directions along which the floor lies in a horizontal position the water level is likewise approximately horizontal. In directions along which the floor varies greatly in elevation the water level likewise varies. Thus in section 1, passing north and south along the one hundredth meridian through Dodge, the same as in sections 2 and 3 having a north-south direction, the water level is approximately horizontal wherever the Cretaceous floor is horizontal. Along the southern portion of section 1, where the upper surface of the Red Beds dips so rapidly to the south, the water level correspondingly falls at the same rate.

In the Cimarron Valley, in the vicinity of Englewood, the water is found at less than 2,000 feet above the sea level, while 25 miles to the north it is found at nearly the same depth below the surface, which makes it fully 2,400 feet above sea level, or 400 feet higher. We therefore have an average inclination of the water level southward along the one hundredth meridian, from Minneola toward Englewood, of more than 25 feet to the mile. In east and west directions we likewise find perceptible inclinations of the water level. Section 5, drawn east and west through Santa Fe, shows a fall of fully 200 feet in 56 miles, while section 6, passing east and west near Garden, shows a decline of the water surface of fully 300 feet in the same distance, or a fall of over 5 feet to the mile.

The same conditions are found to obtain over areas much wider even than that covered by this report. The water in the Arkansas River Valley at Coolidge is no farther from the surface than at Dodge, although the latter is about 860 feet lower, or at Great Bend or Hutchinson or Wichita or Arkansas City, although all the latter points are much lower than Coolidge. Similarly, the water of the high uplands anywhere in western Kansas, in general, is found at about the same depth, whether near the western side of the State or near the eastern limit of the Tertiary, although the difference in elevation may be a thousand feet or more. It is, therefore, correct, in a general way, to speak of the upper surface of the ground water as being approximately level when limited distances are considered, or when a distance extending in a direction which chances to cover a level surface of the underground Cretaceous floor is considered. The elevation contours are consequently of great value in determining the depth to which a well would have to be carried to obtain water if located near a well of known depth. But if the prospective well is to be drilled 5, 10, or 20 miles from any known well the elevation contours would be of but little if any value.

The existence of such vast quantities of water in an arid and semiarid portion of the Great Plains appears very remarkable. Could the thousands of pioneers who traversed these regions prior to the operation of the transcontinental railway lines have known that the purest

and sweetest water existed in such unlimited quantities at so short a distance beneath the surface, how many of them in a few hours' time with spade and shovel would have supplied water to slake the thirst and maintain the life of man and beast throughout the course of those perilous journeys! But the idea of such quantities of water existing within easy reach rarely entered their minds. It took years of occupancy of the Great Plains by thousands of citizens for such an idea to become well established. Even now, after almost ten years of active agitation of the subject, few people outside the immediate localities where such water exists realize the extent to which water may be found.

As already explained, the whole country is underlain by a mass of impervious material, the Cretaceous formations, or the Red Beds. This impervious floor prevents the downward movement of water which may be above it. The Tertiary sands, gravels, and clays furnish a thin and moderately even covering on the top of this floor, a loose, porous covering, well adapted for absorbing all precipitation that may fall upon it and well suited for the transportation through it of water from one part of the country to another. It is not necessary, therefore, that the water under any particular area should have fallen as rain or snow immediately upon that area, but it may have been precipitated tens or hundreds of miles away and traveled by the slow movement now known to exist. Nor is it necessary to assume that all this water must have been precipitated within recent times. There is no reason for believing that climatic conditions on the Great Plains have sensibly varied for thousands of years. The rains throughout this long period have been falling as at present, and such portions of them as were not carried away by the run-off or by surface evaporation or held as soil moisture have sunk to the floor and there await the drill and the pump. As the water accumulates above the impervious floor it first moistens the sand to the degree of saturation, and any excess is held under such conditions that it can be drawn off by proper methods.

As the downward percolation continues, the level at which available water exists gradually rises, so that in the true sense of the term we may speak of the ground being saturated upward, meaning thereby that in the natural order of the events of accumulation the level at which the ground water first became sufficiently abundant to yield a supply was immediately above the impervious floor, and that, with the increase of water from above and from the sides, this level of available water gradually rose in a manner similar to the way the upper surface of water in a vessel rises when water is added. The upward saturation of the sands and gravels, therefore, is dependent upon the accumulation of a larger supply of water from precipitation or from underground movements.

We may think of this body of underground water as existing in

the form of a lake or pool; not a lake with a perfectly level surface, nor one filled entirely with water, but an underground lake the upper surface of which is inclined in any particular direction, dependent upon the relative conditions of supply and exhaustion and the rapidity with which water may move through the sands. Let us again refer to fig. 1, explained in the introduction, the figure representing the underground conditions at Lawrence, in the vicinity of the State University. Here we have a lake in one sense of the term, an area holding an excessive amount of water, so that the smallest opening made in it is instantly filled by the water flowing into it from all sides, just as an opening in a body of water will be filled by the movement of the adjacent water from all directions. But the upper surface of this lake is not level, because the water movement is so retarded that in the lower portions of the ground it can move neither upward nor laterally as rapidly as the supply is brought from above; consequently there is a piling up of the water similar to the way grain may be piled up in a bin.

This represents the conditions in the western part of Kansas, the only essential difference being that the Tertiary sands and gravels permit a more rapid movement than can be obtained in the clays at Lawrence. This great underground lake or sheet of water is consequently uneven of surface and variable in depth. A depression in the floor will be filled or partially filled, so that the water-bearing sands in the valley of the depression will be thicker than on the sides. And yet we may have a floor inclined 10 or 20 feet to the mile, with the water-bearing sands uniformly distributed over it, so that the water will lie at about an equal distance above the surface of the floor over the whole plane.

MEADE COUNTY WELLS.

The Meade artesian area is located in the valley of Crooked Creek, to the northeast of Meade Center, extending from Meade Center to Wilburn. This gives it a length of about 20 miles, with a width in places of nearly 6 miles. The area over which artesian water has been found to a greater or less extent covers from 60 to 80 square miles. It is a broad, flat valley, apparently almost level, with scarcely any irregularities of surface within it, except here and there small drainage channels which are cut downward from 5 to 8 feet, almost like an artificial ditch. On all sides and in every direction from the valley the ground is higher, so that there appears to be a natural wall all around it. On the east and southeast the wall is from 50 to 100 feet high, with gently sloping sides, and the surface is largely covered with sand hills. On the north is a gentle rise toward Crooked Creek, producing a maximum elevation of about 75 feet between the main part of the valley and Crooked Creek itself. But at the northeast, toward Wilburn, the wall is much more abrupt, rising rapidly to a height of 100 *to 140 feet. A few* drainage channels originate in the high ground to

the west and pass across the artesian valley to Crooked Creek. Such channels present the appearance of mere ditches throughout their whole length within the valley, usually having their banks lifted higher than the ground some distance back, showing the filling-in process to have been carried on by them, as is so commonly done by rivers after reaching their base-level. Crooked Creek is, throughout the valley, scarcely distinguishable from some of its tributaries just described. It is almost insignificant in appearance, generally but a few feet wide, and can rarely be observed in the landscape until one is within a hundred feet of it, so closely does it resemble an artificial ditch in its general characters. It has also lifted its banks higher than the adjacent land to so great an extent that in some instances the surface a quarter of a mile away is lower than the top of the bank immediately at the creek.

The uplands to the west of the artesian valley increase in height rapidly, so that the plains to the north and northwest of Jasper, as shown by the Meade topographic sheet, are more than 2,700 feet high not more than 10 miles away, while the general elevation of the artesian valley is between 2,400 and 2,500 feet. The Tertiary ground water of the high plains to the west is found at a depth of from 125 to 150 feet; consequently the level of the water 10 miles to the west of the artesian valley is from 100 to 120 feet above the surface of the valley itself.

The artesian valley throughout is covered with Tertiary or Pleistocene deposits. The thickness of these formations is not known; the different artesian wells vary from 50 to 250 feet in depth, and no one of them has yet passed through the formations. To the north, beyond Crooked Creek, the Benton is shown at the surface in a few places and has been reached in many of the wells. To the northeast, a few miles beyond Wilburn, the Dakota was found by different wells. South of the valley the Red Beds appear at the surface, as the Benton and Dakota gradually grow thinner at the south until they disappear. It is further believed that the strata were here faulted so that the Meade Valley was sunk to an unknown distance, at least 100 to 150 feet, and that it has since been filled in to a considerable extent, probably in Pleistocene time. The character of the materials, as shown in the borings from different wells here and there over the valley, can not be distinguished from the Tertiary materials adjacent on all sides. It is composed of silt, clay, sand, and fine gravel, quite irregularly mixed, so that there is no greater continuity of the bedding planes than may be found in the Tertiary deposits elsewhere.

The mortar beds produced by the cementing of the coarse sand seem to be almost wanting, but here and there the finer sand and clay are frequently partially cemented by calcium carbonate, producing a certain degree of hardening similar to that observed in the mortar beds elsewhere. In character the cement so frequently assumes

a concretionary aspect that it seems probable it was deposited in the sands and clays by infiltrating water after they were placed where they are now found. The artesian water is drawn from the Tertiary or from Pleistocene beds composed of materials in every respect similar to the Tertiary materials surrounding the valley upon all sides. It seems sharply distinguishable from the Dakota artesian water known to exist to the north and northwest.

The whole of the artesian valley is supplied with the ordinary underground water, which may be found at from 5 to 15 feet below the surface. Its abundance is not known, as no one cares to use it. It would seem that it is sharply distinguished from the deeper-lying artesian water, as it has no apparent artesian properties. But at the same time it must be admitted that we are in relative ignorance regarding the reasons why the two are not connected.

The artesian wells at present in successful operation number considerably more than 300, an exact enumeration of them not having yet been made. In depth the wells vary greatly, some of them being but little more than 50 feet deep, while others are as much as 250 feet. There is a strong similarity between the materials passed through by all the wells if considered in a general way, but a lack of similarity if considered in great detail. Each one passes through the surface soil, below which it encounters alternations of clay, sand, and soil. The sand is frequently partly cemented, so that the well drillers speak of it as rock, but the layers thus cemented are rarely more than 12 inches thick, and frequently not more than 6 inches. Two wells within 40 rods of each other found a great variation in the number and relative position of the beds of clay, sand, and rock, but all of them passed through the same materials. So far as could be learned, there is no particular stratum which must be reached before artesian water is obtained. A mass of bluish clay, the color showing that considerable unoxidized organic matter is contained within it, frequently rests on the top of a bed of uncemented sand, stained yellow with iron rust. Such sand always contains water, generally the artesian water, and indicates by the degree to which the iron oxide is produced that the artesian water is a surface water which has not yet been robbed of its supply of oxygen gathered from the atmosphere.

But few wells have been studied carefully while being drilled. In August, 1896, the writer had a well put down especially for making an examination. It was located on the land of Mr. W. F. Foster, near the center of section 6, township 31 south, range 27 west. The drill used was one rented from Mr. Cooper, a well driller living in the valley. In addition to the bit on the end, a pump was attached so that water was forced down through the drill pipe, causing a constant flow upward outside of the pipe, the current bringing up the cuttings of the drill. In this way it was impossible to tell within a few inches, or possibly a foot or two, of the depth at which a change of material was made unless there was a change in the degree of hardness of the

VIEW OF MARR'S ARTESIAN WELL, MEADE, KANSAS.

ıl, so that the one turning the drill could detect the difference. ll was carried to a depth of 167 feet and obtained a moderate water from a loose, yellow sand.

l of Mr. W. F. Foster, on section 6, township 31 south, range 29 west.

f m.	Thickness of stratum. feet.	Description of stratum.	Total depth to bottom of stratum. feet.
....	7	Soil and subsoil	7
....	13	Mortar beds, almost entirely free from sand or gravel small concretionary mass of calcium carbonate intermingled with the clay	20
....	11	Light-colored clay, grading into gray and grayish-blue in color	31
....	5	Blue clay which grades into No. 5	36
....	4	Light-colored clay which grades into No. 6	40
....	10	Blue clay	50
....	2	Mortar beds similar to No. 2	52
....	14	Blue clay	66
....	19	At depth of 66 feet began striking thin layers of hard substance, which seemed to be layers of sand sufficiently cemented with calcium carbonate to produce considerable resistance to the drill. Three or four of these were passed during 19 feet. They were separated from each other by beds of blue clay	85
....	3	A fine white sand at the top, grading into bluish sand at the bottom, and which was sufficiently cemented with calcium carbonate to produce a relatively solid rock	88
....	3	Blue clay, at the bottom of which was a hard sandrock similar to those above	91
....	11	Clay, with sand intermingled	102
....	3	Light-colored sand	105
....	1	Soft clay, grading into No. 15	106
....	6	Alternating layers of clay and sand sufficiently cemented to be noticeable	112
....	18	At 113 feet struck unusually for this well hard sand rock less than 1 foot thick, below which there was a frequent alternation of clay and sand partially cemented, the layers being from 2 inches to 6 inches thick	130
....	20	At about 130 feet a fine sand with clay was struck, a light bluish-yellow in color, which was 20 feet thick	150
....	10	At 150 feet the color changed to more of a reddish-brown	160
....	7	At 160 feet the sand became coarser and the clay redder in color. The drill gradually sank of its own weight, occupying less than two minutes in sinking 3 feet, while the pump was kept running. At the bottom of this formation the clay seemed to disappear almost entirely, and the artesian flow came from the coarse, yellowish sand	167

s learned from Mr. Foster and the parties who did the drilling well previously drilled, located not over 40 rods to the west, almost none of the harder material. The house well of Mr. a quarter of a mile to the east, one of the best wells in the likewise struck none of the harder materials. Each of these lls was drilled in about four hours' time, which further shows : character of the materials passed through. It was reported 'ew wells not more than 50 feet deep have produced consider- ıounts of artesian water. From this they increase in depth to ıum of 250 feet, the depth of a well drilled on Mr. Cooper's ıbout 2½ miles to the southwest of the Foster well.

. but one exception, no well has yet been drilled in this valley nough to admit *more* than a 3-inch pipe. The drills that

have been available for use have been owned locally, and have been handled by men who have had but little experience in well drilling outside the valley. Usually a gas pipe from 12 to 18 feet long is put down to shut off the first water, after which no piping is used. In a few instances wells have been piped almost their entire depth. The best now flowing gave but little water when first drilled. They had a mild flow bringing up sand, the flow increasing as more sand was brought out. In some cases two or three wagonloads of sand have thus been thrown out by the water, after which time the flow reached a maximum amount and the movement of sand almost ceased. Little experimenting has been done to determine whether or not an increase of water could be produced by properly piping the wells, or by pumping them vigorously until all the loose sand was removed. It is quite possible that flows could be greatly increased by these methods.

An artesian flow may be found almost anywhere over the valley. Yet there are many instances in which wells have been drilled that did not yield a sufficient quantity of water to be of value. It is difficult to decide, with the data at hand, why some of the wells are successes and some are failures. In a few places the surface elevation seems to be a little too high. A well in the bottom of a ravine will yield a pretty good flow, while in one drilled on the banks near by, the water will rise almost to the surface, but not high enough to flow. In other instances two or more wells may be close together with the surface elevation the same, some of which will be good flowing wells and others not. It seems probable that this difference is due to two or more causes. The great diversity in the character of the material passed through in drilling the different wells makes it certain that the clay beds are irregular in formation and distribution. One can well understand how the disposition of these beds may cause a variation in the results obtained. A mass of clay may carry the water so deep that the drill can not reach it. Or it is possible for a mass of sand to be entirely surrounded by an impervious clay, so that a drill penetrating the sand will receive no flow because there is no pressure on the water the sand contains. The heterogeneous character of the clay beds, therefore, may be one of the main causes for such differences in wells so close together. The experience with wells which are of little value for weeks, or even months, after which time they become strong flowing wells, shows that in some way they become choked with sand, permitting only a mild flow until the sand is removed by pumping or otherwise.

It seems that the northern and western sides of the valley are the more productive. At present the best wells are in the northwestern portion of the valley, but flowing wells have been obtained all the way from Wilburn, on the northeast, to Meade, or possibly a mile or two south of Meade, to the southwest. The flow of the wells varies *from a pailful* in five minutes to 45 gallons per minute. Approxi-

VIEW OF VICK'S ARTESIAN WELL AND RESERVOIR NORTH OF MEADE, KANSAS

ate measurements have been made of twenty or more of the strong- wells. A large bucket was accurately measured and filled by the w a number of times, one person handling the bucket, the other lding a watch to determine the number of seconds required for ling the bucket. The test was repeated a number of times to elimi- te errors of observation as far as possible. In this way it is believed e probable error of measurement is not greater than 1 or 2 per cent. ve or six different wells were found to yield 45 gallons per minute. venty or thirty exist which yield 30 gallons per minute or more, om which the wells grade downward to the minimum flow.

The water obtained from the wells is largely used for irrigation rposes. Many of the wells were simply left flowing, and the water lowed to waste, without any attempt to use it. The number of acres igated is far less than the estimated possibility.

From data already given regarding elevations in the artesian valley id the uplands to the west, it will be seen that the water level from to 15 miles to the west of the valley is considerably higher than the rface of the ground within the valley. The wells along the arroyos the west of the artesian valley have artesian properties which grad- ally decrease westward. The depth of the water on the uplands to e west is nearly as great a mile away as it is 5 miles away, except- g where the well is located in an arroyo of considerable depth. It ill not do, therefore, to consider the water on the uplands as moving stward under favorable conditions for creating a pressure through- it the whole distance, but rather it should be considered that the npervious Cretaceous or Red Bed floor slopes to the east at nearly e same rate as the surface, and that the water is gradually moving wn this gentle incline toward the east. Here and there, however, passes under local clay beds, which carry the water to lower levels an it otherwise would occupy, and a corresponding pressure is set p. In some way, as the large artesian area is approached, the water scends, and in the descent passes underneath the clay beds of the lley, so that a limited pressure is established.

A few experiments were made to test the height to which water ould rise in an open tube at the well. All such experiments show at the rise is only a few feet, perhaps always less than 20. The essure which causes the flow from the wells, therefore, can not be e to the extra height the water has 10 miles to the west, otherwise e head would be much greater and the flow correspondingly stronger. would seem rather that the pressure is due to the head generated the gentle dipping downward of the water level as it passes under e clay beds near the west border of the artesian area, perhaps rarely tending farther away than from 2 to 4 miles. The water in the rtesian wells seems to be continuous with the general upland water the west. It is like it in character, and the two areas are connected various wells.

Springs throughout the artesian valley are by no means unknown.

A few are located in arroyos along the western border. The most noted area for springs is in the vicinity of Mr. Simms's ranch, a mile and a half north of Fowler. On the eastern side of Crooked Creek, a fourth of a mile or more away, a large area is so abundantly supplied with springs and seeps that hundreds of acres of land are rendered worthless. The springs are principally located just along the border line between the valley proper and the higher lands to the east. The rank growth of vegetation produced by the moisture has provided a tough and heavy sod which protects the softer ground beneath, so that the range animals can pass over it with safety, except in the immediate vicinity of the strongest pools. Here the upward movement of the water is so rapid and the sand which is frequently brought up with the water accumulates to such an extent that vegetation does not grow for a few feet around the springs. Such areas are death traps to range animals. Mr. Simms stated that numerous instances have come under his observation of animals becoming ingulfed in the mud and sinking out of sight, or, if not out of sight entirely, sinking the full length of the body. In many of the springs, by using a long pole, one can feel bones at a distance of from 8 to 15 feet below the surface, presumably those of buffalo and other wild animals which lost their life in the springs. It seems probable that these springs and the artesian wells receive their supplies from the same source. The character of the water is the same; the location in general is the same; for artesian wells can be obtained in the immediate vicinity of the springs, and the whole character of the surroundings implies that there is no essential difference between the sources of the two classes of water. The location of the largest springs is near the southeast valley line, along the eastern side of the valley. If the valley has been dropped by faulting, the water-bearing sands in the valley are doubtless on a level with the Red Beds, or the underlying Dakota on the east. This condition would cause springs to be more abundant along the east line than elsewhere.

Farther south, along the western tributaries to Crooked Creek and in the valley of Crooked Creek itself, springs and seeps abound. The largest amount of spring water flows through Spring Creek, a stream about 3 miles south of Meade. Springs are abundant throughout almost the entire length of this stream, but are particularly so about 3 miles south of Meade, in section 21. Here most beautiful springs exist. At one place with an area of not more than 10 square rods, the cold, clear water comes bursting forth from under the mortar-beds bluff, forming a stream like a mill race. An approximate measurement from this one area gave fully 3 second-feet, which is equivalent to more than 2,000 acre-feet, or enough to irrigate more than 2,000 acres with 12 inches of water each year. This is one of the most remarkable groups of springs anywhere in the West. It would *seem* that there is an abundance of water, however, in this one little *stream to irrigate* more than 3,000 acres 12 inches each year, provided

HEAD OF IRRIGATION DITCH SUPPLYING THE "CROOKED L" RANCH, MEADE COUNTY, KANSAS

Ditch to left. Spring Creek to right.

ere all used for irrigation purposes and proper care taken to guard inst waste. About a mile below this group of springs a ditch ws water from Spring Creek to irrigate the alfalfa fields on Crooked nch. The remainder of the water passes on down the creek, and rincipally used for stock water, although here and there small ounts are taken for irrigation. South from Spring Creek the next t important tributary from the west is Stump Arroyo, a stream ng which frequent springs occur, but which does not yield nearly nuch water. One principal ditch draws water from this creek to us below. All these springs are in the true sense connected with artesian area to the north, and the discussion of them is relevant e, because they throw light on the origin of the water in the sian valley.

Reviewing the whole matter regarding the origin of the water in artesian wells and artesian springs, it must be admitted that it ns the water is continuous with the ordinary underground water he west, and that it is therefore a part of the same. It is certainly inct from the Dakota water, and is so deep that we can not think es above the eastern extension of the water plane on the west.

is of great practical importance to arrive at some conclusion arding the amount of available water in the artesian valley, and ecide whether or not the continued use year after year is liable to roy the supply. It will hardly do to assume that wells could ut down every few rods over the entire valley, each one of which ld flow independently of the others. Artesian water in almost places thus far observed in any part of the world has been found wells which acted sympathetically with one another. When a ng-flowing well is closed, ordinarily adjacent wells have their flow elerated. Few experiments have been thus far made in the Meade sian valley to determine the influence of one well upon another. ry inquiries were made of citizens here and there in the valley, conflicting statements were given on these subjects. Some indi- uals were positive that the rapid flow of one well sensibly dimin- d the flow in weaker ones near by, while other farmers as phatically stated that on their farm the flow of one had no influ- e on the flow of another. It is probable that the former class of orts are correct; in fact, it would be quite remarkable were they not. his condition need not necessarily argue against the large supply vater in the valley. In all cases where wells are close together y mutually influence one another, provided the rate of flow ough the water-bearing strata—sand, gravel, or whatever it may -is not sufficiently great to maintain the flow as long as the supply s. But most beds of sand and gravel are so close grained that re is an appreciable check in the rate of movement of the water in sand, which in most instances will result in the sympathetic on of adjacent wells.

It appears to the writer, therefore, that the question of supply of water for artesian wells depends more on the source of the water than it does on the mere rapidity of the flow from any well or from a group of wells. The facts already given certainly imply, as has been seen, that the source is the ordinary ground water to the west and northwest. If this is correct, the question of supply is essentially the same as the question of the supply in the upland areas. So long as water exists on the uplands from 5 to 20 or 40 miles away, it is probable that it will likewise exist in the artesian wells. Could a sufficient number of wells be drilled, and could the flow be continued from all of them a sufficient length of time, it seems reasonable to suppose that a diminution of the supply of water on the uplands would first be observed, and later of that in the valley. It is probable that the small area, less than 100 square miles, in the artesian valley and the valley of Crooked Creek below Meade, could drain the whole of the uplands to the west, and that their supply of water would not become exhausted so long as there was any available water anywhere in the broad plains to the west or northwest. We are therefore brought to the consideration of the amount of this ground water, a subject discussed later in this report. It is sufficient to say here that, in the judgment of the writer, water enough could be obtained, were it properly husbanded, to irrigate such parts of the Meade artesian valley as anyone is likely to want to irrigate during the next half century.

QUANTITY OF TERTIARY GROUND WATER.

DIFFICULTY OF ESTIMATION.

No one can give more than a mere approximation of the amount of Tertiary ground water in western Kansas. The wells which thus far have been drawing their supply from it, with but few exceptions, have shown no indications of failing. A few wells which were located on the outer margin of the water area have been known to become exhausted by rapid pumping. Others which have only penetrated the water-producing sands a few inches, or a foot at most, have likewise been known to fail. But no instances have yet been found of a well failing, or seeming to be in failing condition, provided it was unquestionably within the water-producing area and had a depth of 5 feet or more in the water-bearing sand. Of course this does not necessarily mean that the supply is inexhaustible, in the true sense of the term. But it may well be taken to mean that with any moderate amount of pumping—even an amount several times greater than has yet been pumped—the supply will not be found wanting.

It is supposed, and perhaps correctly, that water is more abundant in the Arkansas River Valley than on the uplands either north or south. More decisive pumping tests have been made here than at any place on the uplands. The city well at Garden represents the severest

WINDMILL AND RESERVOIR AT GARDEN KANSAS

made within this area, a supply sufficient for a town of 2,000 abitants being furnished. The largest pumping plant within the e is located in the Arkansas Valley, at Hutchinson. Here the chinson Packing Company have three pumps which have been ning constantly for several months, pumping at the rate of about 0 gallons per minute, the equivalent of 5,616,000 gallons per day, hout appreciably affecting the water supply. This is almost 3 sec--feet, an amount approaching the flow from the big springs already cribed along Spring Creek. There is no reason for believing that amount of water here is any greater than anywhere else in the ey from Coolidge to Arkansas City. A like amount, probably, ld be pumped from every quarter section of land within the whole ley. Should such pumping be done all at once, it doubtless would rease the supply, but no fear need be entertained that the water l not be sufficient for all demands that will be made upon it for a g time in the future.

ould the water level in the valley be appreciably lowered, it is te evident that water would be drawn into the valley from the and areas to the south, and to some extent from those to the th. The rapidity with which the movement toward the river ld be made would depend upon a number of conditions, such as degree of exhaustion and the character of the material through ch the movement takes place. Should the draft be sufficient ower the water in the valley 20 feet, there would result a high le of inclination on the upper surface of the water at either side, ling to set up a rapid movement from both sides into the valley. , a gradient of 20 feet to the mile is less than now exists under nal conditions in the area to the north and west of Englewood, yet the water is not drawn away so rapidly but that it is almost ywhere present. Should any other area be appreciably exhausted he excessive pumping from a well, or a group of wells, so that the er surface of the water would be materially lowered, water would in from all directions to supply the deficiency, and in this way one well would drain a considerable area.

is therefore exceedingly difficult to draw decisive conclusions rding the sum total of the water in the Great Plains of the West, ging from the amount that any given well or series of wells may luce, so long as the pump does not entirely exhaust the area. All can be said with certainty at the present time is that, with the e amount of pumping which has already been done, no indica- s of exhaustion have yet been observed.

SOURCES OF TERTIARY GROUND WATER.

is of great importance to consider the sources of the supply and rapidity with which the supply can be transmitted to different lities. Should we look upon the ground water as constituting a t *reservoir, it is evident* that the amount would become entirely

exhausted unless there were a corresponding continuance of the supply. Should pumping be begun from Lake Michigan, it would sooner or later entirely exhaust that vast body of water were it not for the large additions to its volume every year by the surface drainage of adjacent territory. It is possible to determine the amount of pumping that could be done without appreciably lowering the water in the lake, by an estimation of the amount of water added by the surface drainage year by year. Likewise the question of the supply of water for western Kansas is largely one of the rate of the renewal of the ground water. Any estimation on the subject which neglects this factor will in practice prove to be faulty, should the time ever come when the sum total of exhaustion is more rapid than the rate of supply. Enough is known on the subject to demonstrate that pumping from the underground reservoir must be many times greater than that which has yet been done before the exhaustion will nearly equal the rate of supply. In many places throughout the country springs of great strength abound, and lesser seeps supply water to pools and living streams. Should the exhaustion by pumping be appreciable, it would first be noticed in the rate of flow of the springs and seeps. Nothing of the kind has yet been observed.

The original source of all the Tertiary waters is precipitation. The areas over which this precipitation falls are large and varied. In Meade County the average rainfall is about 18 inches per annum, a rainfall which varies from year to year and from month to month. Sometimes heavy falls are known, reaching from 3 to 4 inches or more at a single storm. With such storms an undue proportion of the water runs off through the drainage channels, leaving perhaps less than half to be absorbed by the ground. At other times the rain is so light that it will wet the ground for only a few inches, and entirely evaporate within a few days or weeks, so that perhaps no appreciable part of the lighter rain joins the general ground water.

The character of the soil has a great influence on the run-off. In the sand hill area to the south of Arkansas River and to the east of Crooked Creek, and in the southeastern corner of Meade County, it requires an unusually heavy rain for any of the water to join the run-off, the whole of it being absorbed and held by the porous sands. On the uplands, where the Plains marl is abundant, as well as in the river valleys, where a similar soil exists, the character of the soil is such that only a small amount of the rainfall is absorbed, while a correspondingly large proportion joins the run-off. The conditions of the rainfall and the character of the surface soil over the whole of the Tertiary of western Kansas and eastern Colorado are about the same on the average as in the area covered by this report. Probably more than half of the total precipitation falls in severe storms, or in light rains. We have, therefore, unfavorable conditions for the absorption by the ground of a high per cent of rainfall. No one has

ade any accurate observations on this subject with a view to deter-
ining the per cent of the total rainfall which is absorbed by the
ound; but, as seen in the Introduction, it is only a small part of the
tal amount absorbed that ever becomes available as water supply.
The Tertiary formations extend west, in some places reaching almost
the Rocky Mountains, but in other places they are separated from
e foothills by the high ridge known as the "Hogback," and by the
gh divide farther north. Toward the mountainous area generally
e rainfall increases, so that the average annual precipitation is
eater than in the west of Kansas.

A great deal has been said and written regarding the probability
iat precipitation in the mountainous region will reach western Kan-
is. It may be added that little, if anything, is positively known on
ie subject. We have the Arkansas River carrying its waters all the
ay from the mountains through the Great Plains. The eastward
ielination of the surface is such that the water in the bed of the
tream at one place is higher than the uplands only a few miles below.
Iere and there throughout its course the Benton or Dakota bluffs hem
he water in, so that it is confined to the channel of the stream. At
ther places such impervious bluffs do not exist, and the loose, porous
Tertiary sands and gravel spread from the uplands directly down into
the river valley. There are many places where, so far as the eleva-
tion of the underground floor itself is concerned, underground water
may be drawn from the Arkansas River and spread over all the vast
plains lying below. Whether this actually occurs or not can be deter-
mined only by a careful and detailed study of the water levels north
and south of the river. At present we have so few wells in the great
sand-hill area south of the river in Kansas and Colorado that no con-
clusion of value can be reached in this discussion. The level lines
have shown that the water in the wells 6 or 8 miles south of the river
at Garden is at a little lower level than the water in the river itself.
The same in a general way is true at Dodge.[1] Later investigations
have added but little information on this subject for the areas covered
by the sand hills, the difficulty being that so few wells here exist.

From the meager data at hand, we are forced to conclude that at
different places throughout its course, so far as the water gradients
are concerned, ground water might be deflected from the river valley
southward in its eastward movement and ultimately become a part of
the great body of ground water on the plains only a few miles farther
east. If such deflection ever occurs, we have a mass of water gathered
from the rains and melting snows in the mountainous area being
carried across the divide by the Arkansas River and ultimately spread-
ing over the high uplands to the south of the river. This is only one
of the conditions which are possible, so far as the information now at

[1] Report on Irrigation. 1893. Artesian and Underflow Investigation. Fifty-second Congress, first session, Senate Ex. Doc. 41, part 2, pp. 26-27, pls. 10 and 11.

hand indicates. It is entirely improbable, however, that any considerable proportion of the water in the plains south of the river comes from the river itself. It is probable that if a detailed examination were made it would be found that the water in the sand-hill region is a little higher than in the river. This statement is made because it is customary for rivers to serve as drainage channels rather than as supply channels. The usual condition is for underground drainage to be from the uplands into the rivers, the same as the surface drainage.

Should a considerable proportion of the water be deflected from the Arkansas River Valley to the plains at the south, we should find a much larger amount of water south of the river than exists to the north, unless there is a similar deflection in places to the north. There are some reasons for thinking that this may be true. Farther east, in Clark, Comanche, Kiowa, Pratt, and Stafford counties, and the level lands to the east toward Wichita, there is a larger proportion of springs and streams with living water in them than we find in general to the north of the Arkansas. But it must be confessed that with so few absolute data as are now available regarding the actual amount of ground water, arguments pro and con on this question are of little worth. A careful study of the subject would be of value.

At different places along the Arkansas, where the bluff lines of the valley are composed of Tertiary material, both in Colorado and Kansas, soundings should be made at frequent intervals to determine accurately the level of the ground-water surface both north and south of the river. If it should be found that there is a uniform rise of the level outward from the river, this would show that the underground drainage is uniformly toward the river rather than away from it. If, on the contrary, at any time during the year in periods of high water it should be found that the ground water at or near the river is higher than at localities farther back to the south or north, this would seem to show the possibility, and even the probability, of water being deflected from the river toward the general uplands. The direction of the movement need not be at right angles with the river, nor nearly so, but probably would be in directions somewhat similar to those usually followed by drainage channels which draw water from the river. If such lateral deflections of ground water are made to appear probable, there can be no doubt that at least a portion of the precipitation over the mountainous areas drained by the Arkansas and the Platte rivers may become spread out over the great upland plains and furnish an essential part of the plains ground water. If, on the other hand, such deflections of ground water in the river valleys are shown to be impossible, it may well be doubted if any of the mountainous precipitation joins the ground water of the plains.

It must be remembered that the underground movement is governed largely by the character of the surface of the underground

ST JACOB'S WELL, CLARK COUNTY, KANSAS

eous floor which has already been described. There are strong ic reasons for believing that this Cretaceous floor in most east of the foothills has a greater elevation than the under- d water level in the great trough-like area trending north outh to the west of the "Hogback" and the high divide, so he eastward motion of the water would be impossible, except and there where there might be a channel or depression in retaceous floor similar to those along the Arkansas and Platte

atever conclusion may ultimately be reached regarding the ility of an eastward underground movement from the moun- themselves, the rate of the movement of the water through the is, after all, of the most importance. When water is being ed from a well, it is not so important to know the amount of 10, 50, or 100 miles away, as it is to know the rate of move- through the sand of the water immediately adjacent the well. naximum supply that the well can furnish will be dependent the rate of the inflow to the well, and only remotely upon the otal of the water over the whole area. The rate of movement ewise of great importance in considering the total amount of ble water on the plains as a whole.

uld the precipitation and the proportion of the precipitation joins the ground water be greatly increased, unless the possi- te of underground movement were correspondingly increased, ble masses of water would tend to pile up where the precipi- occurs, without sensibly affecting the supply in other parts of untry. Those who believe in a mountainous source for a part whole of the plains water must therefore be able to show he rate of eastward movement is sufficiently rapid sensibly to se the available water at different places on the plains. Other- he increased precipitation in the mountainous areas would be avail.

doubtful if laboratory tests are of much value in this discussion, se the conditions governing them are not applicable. The incli- n of the surface, the porosity of the strata, the ease with which may pass from one stratum into another as the strata become dis- nued, are some of the questions which must be considered. In xperiment neglect of any one of these conditions, and probably s not yet fully understood, will cause the results obtained to be le if any value in this consideration. We may have a mass of or gravel largely composed of coarse grains or pebbles, so that t thought it would seem that water would flow freely through f, however, there is a small amount of silt or clay disseminated gh the mass, this will have a most important influence. The e masses of gravel in such cases not only do no good, but do ; for each grain, being impervious, renders just that much space

impervious. It is probable that the rate of flow through a heterogeneous bed of this character is governed by the finest materials in the bed. Investigations of the subject, therefore, must consider the detailed geologic conditions of the area studied.

SUMMARY.

In summarizing the foregoing discussions regarding the amount of water, it may be concluded that there is a surprisingly large amount of water in the Arkansas Valley, and a similarly surprisingly large amount on the uplands, although perhaps smaller than in the valley. The springs along Spring Creek are the best single evidence we have of the large amount on the uplands, and the pumping tests in the valley, particularly at Hutchinson, are the best tests we have of the amount in the valley. These, combined with the almost universal presence of water, and the meteorologic and geologic conditions already explained, furnish good reasons for believing that the amount of ground water under the area here described is sufficient to meet any demands that will likely be made upon it, even should industries spring up in the West which will use many times as much water as now seems probable. The greatest needs for western Kansas now, and for the whole plains area, are better methods of raising water from beneath the surface, and better methods in using it.

IRRIGATION DEVELOPMENT.

Irrigation is now practiced to a considerable extent in the Arkansas Valley and along the Cimarron River and Crooked Creek. Numerous small reservoirs and irrigation pumps are also established on the uplands, some of which have proved to be surprisingly successful. In the valleys the principal crops raised by irrigation are alfalfa and fruit, but on the uplands little is irrigated besides gardens and fruit.

The water in the Arkansas River is so low during the greater part of the year that the canals are dry, but in times of freshets they are used to a considerable extent, and the thousands of acres of alfalfa and orchards and other crops are quite thoroughly irrigated once a year at least, and upon the average two or three times. This is sufficient to produce a moderate crop of alfalfa during a dry year, while in an ordinary season it will give from three to four cuttings of hay.

The acreage varies from year to year, depending upon many matters which affect the prosperity of the farmers in that part of the State.

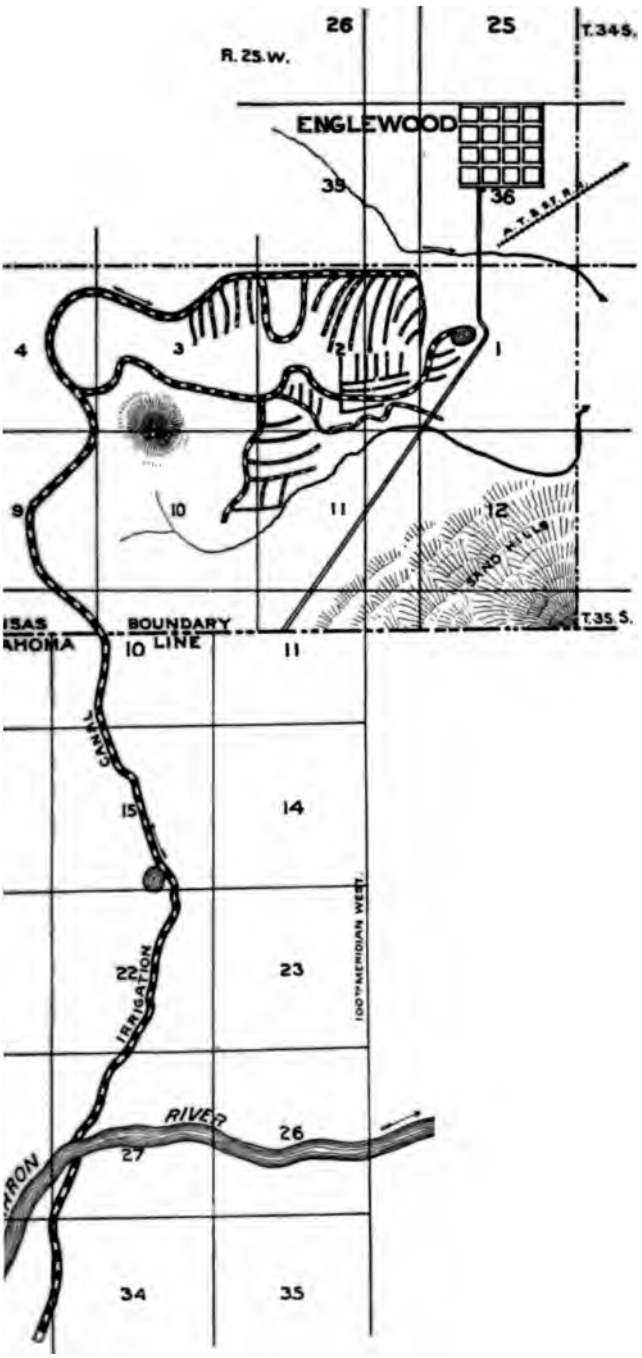
Several hundred acres are also irrigated in the valley from pumps. In most places the water is raised less than 12 feet, so that windmills are very efficient, a 14-foot wheel furnishing ample power to run an 8-inch pump that will throw from 5 to 8 gallons at a stroke. Irrigation from mills is on the increase, as it frequently happens that dry weather in the spring and early summer is disastrous before water *from the* river is available.

HEAD OF PERRY IRRIGATION CANAL, CIMARRON RIVER, NEAR ENGLEWOOD, KANSAS.

narron River carries a large amount of water during a part of ear and is rarely dry in this part of the State, as it is fed by gs from the ground water. Irrigation is practiced to a consider- extent in different places along the valley. The largest tract r water from the river at present is the Clearmont ranch of Col. . Perry, at Englewood. This ranch at present has about 1,100 under ditch, but Colonel Perry's plans are to reduce this amount 0 acres, as he thinks the same amount of labor expended on a ler acreage will give better returns than when spread over a r piece of land. Formerly general farming was conducted at ranch, but it has been found that with the markets as they have ıtly been it is more profitable to raise feed for stock and to mar- he animals. During the summer of 1896, therefore, no field crops nsequence were raised except alfalfa, sorghum, and kaffir corn, of which grows with great luxuriance. Pl. XII is a map of Clear- ranch, showing how the water is drawn from the Cimarron and rincipal laterals employed in distributing it over the ranch.

certain times in the year the water in the Cimarron is slightly , particularly in dry weather. This apparently produces no bad effects, principally because the most irrigation is done at times the river is flush and consequently the water least salty.

e large amount of water furnished by the springs of Spring Creek rtially used on the Crooked L ranch, which lies in the valley at junction of Spring Creek and Crooked Creek. Here about 500 are under irrigation, devoted principally to alfalfa, the water hich is drawn from Spring Creek. Pl. VIII is reproduced from otograph, showing the head of the supply ditch. Below the mouth ring Creek a few small fields are irrigated from the creek, but so large as the Crooked L ranch.



MONT RANCH, NEAR ENGLEWOOD, KANSAS, SHOWING HOW WATER IS DRAWN FROM THE CIMARRON AND THE PRINCIPAL LATERALS.

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n agriculture by irrigation in the western part of the United States at the enth census, 1890, by F. H. Newell, 1894, quarto, 283 pp.

ntains a general description of the conditions of irrigation in the United States, the area and cost of works, their value and profits; also describes the water supply, the value of , of operating wells, canals, and other details; then takes up each State and Territory ately, giving a general description of the condition of agriculture by irrigation, and discusses physical condition and local peculiarities in each county.

th Annual Report of the United States Geological Survey, 1892-93, in two s, Part II, Accompanying papers, 1894, octavo, 597 pp.

ntains papers on potable waters of the eastern United States, by W J McGee; mineral and waters of the United States, by A. C. Peale; results of stream measurements, by F. H. ell. Illustrated by maps and diagrams.

1895.

h Annual Report of the United States Geological Survey, 1894-95, Part II, rs of an economic character, 1895, octavo, 598 pp.

ntains a paper on the public lands and their water supply, by F. H. Newell, illustrated by ge map showing the relative extent and location of the vacant public lands; also a report he water resources of a portion of the Great Plains, by Robert Hay.

ical reconnaissance of northwestern Wyoming, by George H. Eldridge, 1894, 76, 12 pp. Bulletin No. 119 of the United States Geological Survey; price, nts.

ntains a description of the geologic structure of portions of the Big Horn Range and Big n Basin, especially with reference to the coal fields, and remarks upon the water supply and mineral possibilities.

f progress of the division of hydrography for the calendar year 1893-94, by . Newell, 1895, octavo, 178 pp. Bulletin No. 131 of the United States gical Survey; price, 15 cents.

ntains results of stream measurements at various points, mainly within the arid region records of wells in a number of counties in western Nebraska, western Kansas, and eastern ado.

1896.

th Annual Report of the United States Geological Survey, 1895-96, Part II, omic geology and hydrography, 1896, octavo, 864 pp.

ntains papers by G. K. Gilbert on the underground water of the Arkansas Valley in eastern sas; by Frank Leverett on the water resources of Illinois; and by N. H. Darton on a reconnaissance of the artesian areas of a portion of the Dakotas.

esian prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, vo, 230 pp., 10 plates. Bulletin No. 138 of the United States Geological gy; price, 20 cents.

ves a description of the geologic conditions of the coastal region from Long Island, N. Y., ginia, and contains data relating to many of the deep wells.

f progress of the division of hydrography for the calendar year 1895, by F. Newell, hydrographer in charge, 1896, octavo, 206 pp. Bulletin No. 140 of United States Geological Survey; price, 25 cents.

ntains a description of the instruments and methods employed in measuring streams and results of hydrographic investigations in various parts of the United States.

Bulletins can be obtained only by prepayment of cost as noted above. stamps, checks, and drafts can not be accepted. Money should be trans- y postal money order or express order, made payable to the Director of the ited States Geological Survey. Correspondence relating to the publications of ey should be addressed to **The Director, United States Geological Survey,** gton, D. C.

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1897.
2. Irrigation near Phoenix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier.
8. Windmills for irrigation, by E. C. Murphy.
9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Mesilla Valley, New Mexico, by T. C. Barker.

In addition to the above, there are in various stages of preparation about [illegible] other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following [illegible] in the sundry civil act making appropriations for the year 1897–98:

Provided, That hereafter the reports of the Geological survey in relation to the gauging of streams and to the methods of utilizing the water resources shall be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,000 copies shall be delivered to the Senate, and 3,000 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896; 29th vol. 29, p. 452.)

Application for these papers should be made either to members of Congress [illegible]

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. [illegible]

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 7

SEEPAGE WATER OF NORTHERN UTAH.—Fortier

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 12[illegible] pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-'89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, [illegible] pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-'90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890, also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by [illegible] and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-'91. Contains a report upon the location and survey of reservoir sites during the fiscal year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by [illegible] and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell, quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 151, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892, quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated farms, the total area and average size of irrigated farms in the subhumid regions, the per cent of number of farms irrigated, character of crops, value of irrigated lands, [illegible] of irrigation, the investment and profits, together with a resume of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-'92, Part III, Irrigation, 1893, octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "Engineering and engineering results of the Irrigation Survey," by Herbert M. Wilson; "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893, octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894, quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States by area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical condition and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892-'93, in two parts, Part II, Accompanying papers, 1894, octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W. J. McGee; "Natural mineral waters of the United States," by A. C. Peale; "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 7

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

J. C. Branner

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

SEEPAGE WATER OF NORTHERN UTAH

BY

SAMUEL FORTIER

WASHINGTON

GOVERNMENT PRINTING OFFICE

1897

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR.
UNITED STATES GEOLOGICAL SURVEY.
DIVISION OF HYDROGRAPHY.
Washington, April 20, 1897.

SIR: I have the honor to transmit herewith a paper entitled Seepage Waters of Northern Utah, by Samuel Fortier, professor of irrigation engineering at the Agricultural College at Logan, Utah. The facts herein presented are based upon field work carried on mainly during the summer of 1896, and have special value in illustrating conditions which prevail to a greater or less degree throughout all irrigated lands, especially within inclosed valleys or on long, narrow drainage systems.

One of the matters which most complicate and embarrass the adjudication of water rights and the strict enforcement of priorities of appropriation arises from the fact that a considerable volume of water available for irrigation during the critical season of the year, when the crops are maturing, comes from the seepage from lands higher upstream to which water has been applied earlier in the year. In some cases these lands have been irrigated in defiance of a strict construction of the law regarding the priority of right to use water, but it has been claimed that such use, instead of being a detriment to the lands below, has been a benefit, and, in fact, that there has been more water available in consequence of this use than could otherwise be had. The determination of these matters requires careful measurement and study in each case, but the work of Professor Fortier serves to indicate what may be expected under similar conditions and illustrates methods applicable to this examination.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

SEEPAGE WATER OF NORTHERN UTAH.

By SAMUEL FORTIER.

LOCATION AND PURPOSE OF THE INVESTIGATION.

The term "seepage water" is used by the irrigators of the West to designate the water which reaches the lowest grounds or the stream channels, swelling the latter by imperceptible degrees and keeping up the flow long after the rains have ceased and the snow has melted. The word "seepage" is applied particularly to the water which begins to appear in spots below irrigation canals and cultivated fields, usually some months or even years after irrigation has been introduced, and which tends to convert the lowlands into marshes and gives rise to springs, which in turn may be employed in watering other fields.

The importance of a thorough knowledge of the behavior of seepage water is obvious when consideration is given to the close relationship which exists between the available water supply and the material prosperity of the arid region where irrigation is practiced. This is particularly true of Utah, where every readily available source of supply has long since been utilized and where the rapidly increasing agricultural population necessitates the complete utilization of all fresh waters.

The measurements and investigations of seepage water described in this paper have been confined mainly to Cache Valley, being included within three counties in northern Utah, Weber, Boxelder, and Cache, and one county, Oneida, in Idaho. The conditions may be taken as fairly typical of those in the entire State, and to a less extent of those of adjacent States. A full knowledge of the seepage water will be of inestimable value in the development of Cache Valley, owing to the conditions now existing. The towns and farming communities were settled for the most part from 30 to 40 years ago. The tributaries of Bear River have supplied all irrigating waters, and many of the ditches and canals have water rights extending over a period of 30 years. These early ditches were the first built to divert water from Bear River and its tributaries, and according to the law of prior appropriation which prevails in Utah, Wyoming, and Idaho, the three States through which Bear River flows, the early canals of Cache Valley have water rights prior to all others. Boxelder County has

at least a quarter of a million acres of fertile irrigable land, and with the exception of Boxelder Creek, Willard Creek, and other small streams whose aggregate summer flow does not exceed 40 second-feet it is entirely dependent upon Bear River for the water necessary to irrigate its extensive area.

The time is not far distant when conflicts over water rights will arise between the irrigators of these counties, and it is therefore highly important to collect and record now all the physical data possible pertaining to the capacities of the irrigating ditches, the areas watered by each, and the general behavior of all sources of supply. To put off the collection of such facts until litigation has begun, and to attempt to render court decisions upon the conflicting testimony of interested witnesses only, is full of danger. Moreover, a study of the hydrography of Bear River and its tributaries is complicated, owing to the fact that three States obtain water from this one source. During the next drought many of the irrigators of northern Utah are likely to suffer serious loss from a scarcity of water in Bear River, caused by its diversion through canals in Wyoming and Idaho. If the law of prior appropriation is to be accepted for interstate priorities, it is of the utmost importance that all existing water rights be clearly defined.

There is still another important question which such work may help in solving. It may be stated thus: How much of the water diverted and utilized in the upper valleys returns to the river channel in time to be diverted by lower irrigators? On account of variations in climate, soil, and topography, the results obtained in one section may be worthless when applied to others, and the only way to determine the behavior of irrigating waters is to make the necessary measurements in each valley. Until this work is at least partially accomplished there can be neither a just nor a permanent apportionment of appropriated waters.

The facts upon which this paper is based were obtained during investigations made in the summer of 1896. In this work the writer was ably assisted by Messrs. J. L. Rhead, Thomas H. Humphreys, and John S. Baker. The expenses were borne jointly by the Utah Agricultural Experiment Station, the Division of Hydrography of the United States Geological Survey, and the board of county commissioners of Cache County, Utah. Owing to the large cost of transportation, it was necessary to confine the greater part of the work to Cache County, Utah. In Cache Valley, which comprises the cultivated portions of this county and the southeastern part of Oneida County, Idaho, the field operations consisted in the measurement of every stream flowing into the valley at three different times during the season; also the determination of the capacity of every ditch and canal in the same valley at least three times, and accurate current-meter measurements and daily records of the outflow of the valley through "The Narrows" *on Bear River*. While this work was in progress an attempt was also

nade to locate the head gate and determine approximately the route of each ditch and canal. The results of such surveys are reproduced n the accompanying map (Pl. I). The progress of the field work hroughout the season is fairly well shown by the number of streams nd canals measured each month. From June 15 to 30, 1896, there were 58 measurements; in July, 131; in August, 112; in September, 106; and in October, 19; making a total of 426.

The chief object which the writer had in mind in making a partial ydrographic survey of Cache Valley was to determine, if possible, by daily and semiweekly gagings, the ratio existing between the inflow (diminished by the volumes used in irrigation) and the outflow. This ratio being known for a continuous period of three months, an opportunity is afforded to compare the loss of water due to evaporation with the gain due to seepage. Other objects held in view, of minor importance to the student of hydrography but possessing great value to the irrigator, were the average flow of the various ditches and canals, the amount of the surplus waters of the larger streams, and the duty of the irrigating waters.

There are several hundred natural and artificial water channels in Cache Valley if the main laterals are included. It is safe to assert that prior to June 15, 1896, less than six measurements had been made of these canals and streams. This record does not include the work done since 1889 by the United States Geological Survey, which perhaps comprises fifty stream measurements in Cache Valley alone. It was thought that if each canal and small stream were measured first in June, then during the latter part of July, and lastly about September 1, the results of the three measurements would represent, with some exceptions, the greatest, medium, and least flow during the season, and that the average of the three results might be taken as the average flow of such canal or creek.

ORIGIN OF SEEPAGE WATERS.

The water contained in the open spaces occurring in clay, sand, gravel, and other materials of which soils and subsoils are composed, is known by various names, such as soil moisture, ground water, ground storage, subsurface supply, and the like. When this ground water moves down an inclined stratum of porous materials, the term seepage water seems to be more appropriate than that of ground flow, which many writers have recently used. Seepage water conveys the idea of lateral motion, but when one uses the terms "soil moisture," "ground water," or "underground water," this conception is usually not implied.

The water content in dry soils may be so small as to admit of only a slight vertical movement due to the forces of capillarity and evaporation. On the other hand, portions of soils and subsoils may be completely saturated, but so located that the water confined therein

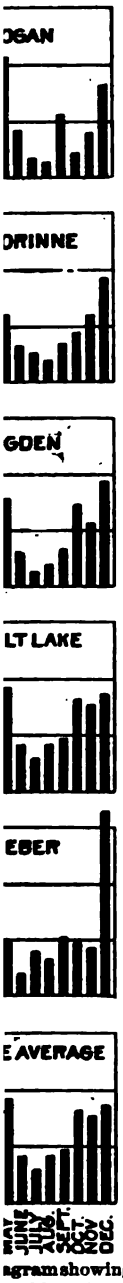
is stagnant. In such cases there can be no lateral flow. Seepage waters as herein defined may be regarded as coming from three sources, which, however, are not always distinct: (1) from uncultivated hillsides and mountain slopes; (2) from irrigated land; (3) from the beds and side slopes of water channels.

It will be readily understood that a complete determination of the quantity of water which comes from that which is stored in the ground, on any particular drainage basin, involves more than a knowledge of the results of the stream measurements made in such basin. It is possible, for example, to ascertain with considerable accuracy the amount of surface water which flows into a valley, the volume used in irrigation, and the outflow, but without knowledge of the losses occasioned by evaporation, the problem of seepage waters is indeterminable. For the want of much necessary information in relation to the precipitation and evaporation of northern Utah, there is herewith introduced in outline some of the more recent observations made elsewhere in connection with the quantities of water evaporated from water surfaces and from ground surfaces or transpired from plant foliage.

In examining the water supply of any section, such as Cache Valley, it is desirable to begin with a study of the rainfall. If the complete history of each raindrop or snowflake were known from the time it falls to the ground until it again returns, in the form of vapor, to the atmosphere, water problems could be readily solved. The total volume of water which falls as rain or snow on any particular watershed may be subdivided into four parts, which vary widely in accordance with local conditions. Of these, one portion runs off the surface and fills the streams, especially during the spring months; a second sinks into the soils and subsoils, enters the fissures of rocks, is absorbed by porous strata, such as sandstones, and is the chief source from which wells and springs derive their supplies and streams their late summer and autumn discharges; a third part of the annual precipitation is evaporated from ground and water surfaces; and the fourth part develops plant growth. From the standpoint of the farmer, that portion utilized in developing plant growth is the most important. Cultivated plants are chiefly dependent on the water which sinks into the ground; hence the importance of the latter to the irrigator.

Relatively too much attention has been given to the surplus flow in springtime and too little to that derived from ground storage. A reference to Logan River may serve to illustrate the difference between that portion of the rainfall which rushes off the surface of drainage basins, either when snow melts in spring or when cloud-bursts occur in summer, and that which sinks into the porous covering of the mountain slopes to issue later as the flow from the ground storage, maintaining the streams during the late summer and autumn months. *During* June, July, and August of 1893, the rainfall as measured at

eriment Station on the basin of Logan River was only one-fourth inch. The snow on the mountain ranges had all melted before the end of July, yet on the 3d of September there was a flow in Logan River of 250 second-feet. Where did this supply come from? The slight rainfall need not be taken into account, for it is safe to assume that an amount many times greater than the rainfall was evaporated. It could not have come from melted snow, because the snow had disappeared as vapor, had run off, or had sunk into the ground long before the expiration of the time named. The only available source was the flow from the ground storage; in other words, the seepage from the mountain slopes.



agram showing
onthly rainfall
at stations in

PRECIPITATION.

The records from a number of important localities where the observations are most reliable have been tabulated by Mr. James Dryden, meteorologist of the Utah Experiment Station. These records extend over past periods varying from three to thirty-three years, and represent quite accurately the precipitation on the valleys and table lands.

The diagrams and tables herein given are compiled principally from information obtained from Mr. Dryden. Fig. 1 is a graphic representation of the precipitation for each month of the year at

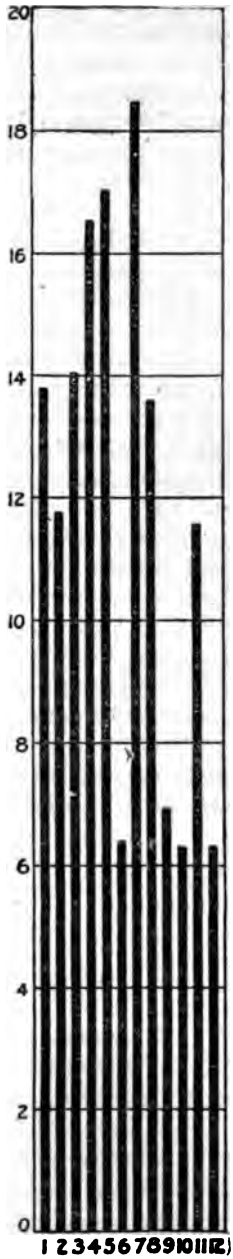


FIG. 2.—Diagram showing mean annual rainfall in inches at 12 stations in Utah.

five northern stations. At Corinne, Boxelder County, the of *greatest rainfall* for twenty-five years has been December,

averaging 1.8 inches. January, February, March, April, and May have remained nearly constant at about 1.25 inches each, while the dry months have been June, July, August, and September, which have not averaged one-half inch each. This distribution of the annual precipitation is typical of nearly every section of Utah. A glance at the diagrams of fig. 1 is sufficient to show that June, July, August, and September are the dry months, and as these constitute the greater part of the period between seed time and harvest, the rain evidently falls at the wrong time.

Salt Lake County, as represented by the rainfall of the city of Salt Lake, has averaged during the past thirty years 16.53 inches, but during the four summer months, beginning June 1, the total average rainfall has been less than 3 inches. From 1870 to 1895, Weber County, as represented by the station at Ogden, has had an average annual precipitation of 14.02 inches, but the four summer months have not averaged one-half inch. The diagram at the bottom of fig. 1 gives the mean monthly precipitation for the State as obtained by averaging the results of the more important stations scattered in various parts and located at different altitudes. This exhibits the deficient rainfall during June and the gradual increase through July, August, and September. Fig. 2 gives the average annual precipitation at twelve important stations, these being arranged in a general geographic order from north to south, the most northerly being Logan, in Cache County, and the most southerly St. George, in Washington County, in the southwestern corner of the State. The numbers at the bottom of the figure refer to the stations named in the table below.

The following table gives for the 12 selected stations the approximate elevation above sea level, the length of the record in years, and the mean annual rainfall during this time:

Mean annual rainfall at 12 stations in Utah.

No. in diagram.	Place.	County.	Above sea level.	Length of record in years.	Mean annual rainfall.
			Feet.		*Inches.*
1	Logan	Cache	4,500	5	13.81
2	Corinne	Boxelder	4,232	26	11.73
3	Ogden	Weber	4,340	26	14.02
4	Salt Lake	Salt Lake	4,354	33	16.53
5	Heber	Wasatch	5,500	3	16.97
6	Fort Duchesne	Uinta	4,941	8	6.35
7	Levan	Juab	5,100	7	18.45
8	Fillmore	Millard	5,100	8	13.60
9	Moab	Grand	3,900	7	6.95
10	Loa	Wayne	6,900	4	6.28
11	Parowan	Iron	5,970	5	12.55
12	St. George	Washington	2,880	15	6.31

Below is given the mean monthly rainfall for the same period:

Mean monthly precipitation at twelve stations in Utah.

Place.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Logan	1.55	1.52	2.05	1.12	2.06	.78	.27	.21	1.60	.36	.74	1.55
Corinne	1.27	1.26	1.29	1.12	1.12	.58	.44	.31	.63	.84	1.07	1.80
Ogden	1.65	1.51	1.57	1.47	1.49	.58	.25	.40	.68	1.42	1.12	1.88
Salt Lake City	1.46	1.31	2.01	2 24	1.76	.78	.55	.75	.91	1.60	1.48	1.68
Weber	2.89	2.16	2.15	1.01	.95	.35	.75	.61	1.08	.94	.80	3.28
Fort Duchesne	.38	.50	.71	77	.79	.25	.48	.63	.60	.24	.23	.77
Levan	1.63	1.83	2.33	2 22	2.07	.69	.40	.77	1.39	1.04	.76	3.32
Fillmore	1.47	1.68	1.65	2.25	1.11	.53	.51	.83	.98	.45	.73	1.41
Moab	.68	.73	.86	.32	.33	.08	.64	.51	.72	.42	.59	1.07
Lehi	.57	.74	.63	.15	.33	.08	.87	1.08	.49	.46	.43	.45
Farowan	1.27	1.56	2.03	1 35	.95	.17	1.09	1.06	1.04	.71	.57	1.00
St. George	1.01	.91	.60	.27	.33	.03	.33	.29	.41	.31	.44	1.38

More than the usual amount of rain fell in Cache Valley during 96, as shown by the following table, which gives the precipitation June, July, August, and September of that year, and also the erages of all past records for the same months:

Precipitation at Logan, Utah, for four months.

	1896.	Prior to 1896.
	Inches.	*Inches.*
June	0.46	0.78
July	1.40	0.27
August	1.49	0.21
September	0.91	1.60
Total	4.26	2.86

EVAPORATION.

Many tests have been made in different parts of the world to ascertain the amount of water evaporated from water surfaces. The utilization of this information is, however, limited chiefly to hydraulic engineers who wish to determine the losses from reservoir and lake surfaces. A knowledge of the actual volumes of water evaporated from such surfaces is of little direct value to Western irrigators, for the reasons that the operating forces are entirely beyond their control and the evaporated water is borne away by the prevailing winds. It might be some satisfaction to know that the evaporation from the surface of Great Salt Lake was only 60 inches yearly instead of 80 inches, some would have us believe; but that knowledge alone might not enable us to reclaim an additional acre of land in Utah, although the difference of 20 inches yearly over the entire surface of the lake would

comprise a volume of water sufficient to irrigate a million acres. There is good reason to believe that little of the moisture withdrawn from the Utah lakes returns in the form of rain or snow within the confines of the State. Tooele County borders on Great Salt Lake, but with a probable annual evaporation of 6 feet near its shore line, the parched soil receives yearly on an average only about 6 inches from rainfall.

Comparatively few measurements of evaporation have been made in Utah. The most important were those carried on at the reservoir in the rear of Fort Douglas, immediately east of the city of Salt Lake.

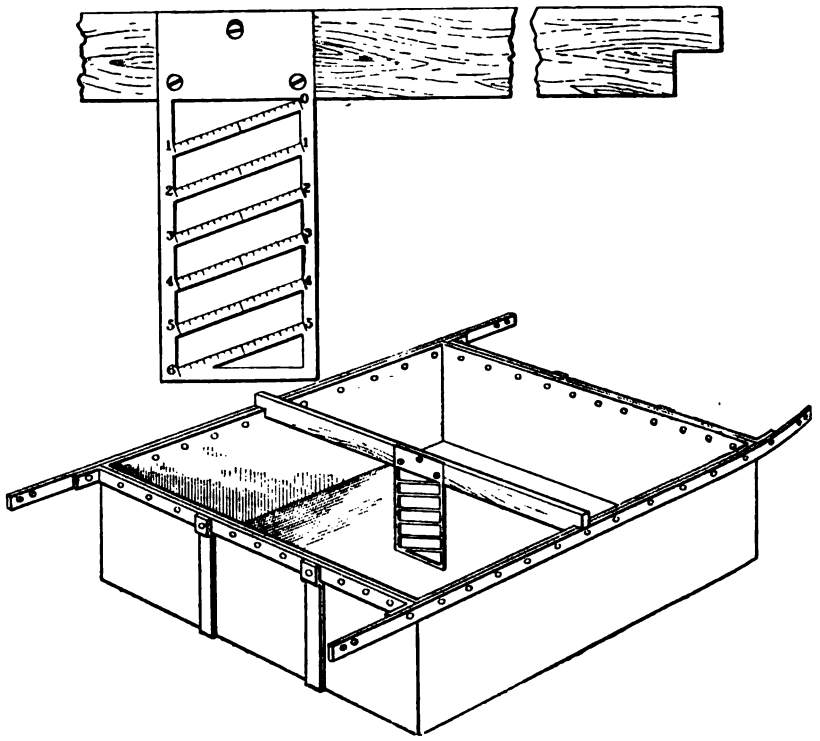


FIG. 3.—Evaporating pan and scale.

These observations are mentioned in the Eleventh Annual Report of the United States Geological Survey, Part II, on pages 30 to 34, and the results are given briefly in the Fourteenth Annual Report, page 154. Similar measurements were made for a few months at Provo and Nephi.

The apparatus used by the Geological Survey in making observations of evaporation consists of a galvanized-iron pan 3 feet square and 10 inches deep, immersed in water and kept from sinking by means of floats of wood or hollow metal. Into this pan water is poured until *the surface is* within from 1 to 2 inches of the top, the attempt being

nade to keep the pan as full as possible without spilling over the dge. The temperature of the water inside the pan has been found y experience to be practically uniform with that of the surrounding ater in the ditch or pond in which the pan is placed, varying from t usually not more than 1 or 2 degrees. If the pan is kept full, so hat the edge or rim does not offer an obstruction to the wind, the vaporation from the surface inside the pan should be approximately he same as that from the surface of the water outside.

The amount of water evaporated is determined by measuring the lecrease in height of water, observations being usually taken once or ometimes twice a day. These are made by means of a brass scale ung in the middle of the pan and provided with diagonal bars upon hich the reading is magnified about three times. By the use of this scale it is possible to read differences in vertical height of one one-hundredth of an inch. This method of observing the height of water is probably not so good as that by means of a hook gage, but is somewhat simpler and the apparatus is less expensive. An improvement[1] has been proposed, consisting of a rod fixed rigidly in the center of the pan and rising to within 1 or 2 inches of the top. Water is put into the pan until the point of this rod is about to be submerged, as shown by the meniscus. As the water evaporates more is added by means of a tin cup made of such capacity that one cupful is equivalent to a lepth of one one-hundredth of an inch on the surface of the pan. The observer has only to record the number of times the cup is filled and emptied into the pan.

The following table gives the results of the measurements at Fort Douglas, the observations beginning on August 23, 1889, and ending n May, 1893. They were made by a soldier, Charles M. Lowry, letailed for the purpose. Owing to numerous disturbing influences, such as heavy wind splashing water into the pan or rainfall adding o the quantity, or, during winter, the freezing of the surface, it was arely possible to continue observations consecutively for more than t few days at a time. The table gives, therefore, the number of days n each month during which fairly reliable results were obtained, and also the average of these daily observations. This average is assumed o be that for all the days of the month, and is therefore multiplied by the number of these to obtain the approximate monthly total.

[1] Physical data and statistics of California, 1886, p 373.

Evaporation at Fort Douglas, Utah, in inches.

Month.	1889.			1890.			1891.			1892.			1893		
	Days.	Mean daily.	Total.	Days.	Mean daily.	Total.	Days.	Mean daily.	Total.	Days.	Mean daily.	Total.	Days.	Mean daily.	Total.
March	....	....	....	....	....	....	....	....	....	15	.067	2.1	....	....	....
April	....	....	....	....	123	3.7	19	.107	3.2	14	.075	2.3	3	.083	2.5
May	....	....	....	....	133	4.1	15	.153	4.8	....	.132	4.1	8	.169	5.2
June	....	....	....	....	170	5.1	22	.174	5.2	25	.177	5.3	....	....	....
July	....	....	....	16	240	7.6	10	.246	7.6	26	.211	6.5	....	....	....
August	11	.340	10.5	20	210	6.5	20	.210	6.5	10	.235	7.3	....	....	....
September	18	.190	5.7	23	153	4.6	17	.174	5.2	25	.174	5.2	....	....	....
October	7	.157	4.9	21	068	2.1	15	.081	2.5	15	.068	2.1	....	....	....
November	2	.035	1.0	15	041	1.2	15	.047	1.4	10	.055	1.6	....	....	....

Observations were conducted in a similar manner at Provo during a portion of the month of October, 1889, giving an average daily evaporation of 0.10 inch, and at Nephi, at intervals during a part of the same year, giving a mean daily evaporation for June of 0.13 inch; for July, 0.16 inch; for August, 0.15 inch, and for September, 0.10 inch. Similar fragmentary results have been obtained for localities in other parts of the West.[1] The longest series, however, is that begun in 1887 by Prof. L. G. Carpenter at the Experiment Station at Fort Collins, Colorado. The evaporating pan at this place is 3 feet square and 3 feet deep, sunk into the ground, the height of water being measured by means of a hook gage. The results have been published only up to the end of 1891.[2]

Monthly evaporation at Fort Collins, Colorado, in inches.

Year.	Jan.	Feb.	Mar	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1887	2.46	3.23	4.60	5.55	5.19	5.75	5.23	4.24	4.12	3.26	1.48	1.60	46.71
1888	....	....	....	....	4.45	7.70	7.00	4.06	3.94	2.17	1.35	0.99	....
1889	1.09	1.03	2.75	4.06	3.72	4.34	5.20	5.15	5.19	3.28	0.62	1.42	37.83
1890	0.86	2.36	3.48	3.50	4.32	5.71	5.44	5.76	3.69	2.71	1.32	1.10	40.24
1891	1.20	2.79	2.23	2.24	5.03	4.97	5.72	4.90	4.12	3.62	1.73	0.75	39.12

At the experiment station located at Laramie, Wyoming, Prof. J. D. Conley noted a total evaporation from April 17 to October 22, 1895, of 37.02 inches, distributed as follows: April 17–30, 2.53; May, 7.33; June, 6.24; July, 7.29; August, 6.07; September, 4.94; October 1–22, 2.62 inches. In this test the evaporation was measured by means of a hook gage within a tank lined with galvanized iron, and holding when full a cubic meter of water.[3]

Prof. T. Russell, in the Monthly Weather Review for September,

[1] Eleventh Ann. Rept. U. S. Geol. Survey, Part II, p. 34.
[2] Fourth Ann. Rept. State Agricultural Experiment Station, Fort Collins, Colorado, 1891, p. 53.
[3] University of Wyoming Experiment Station Bulletin No. 27, March, 1896, Meteorology for 1895, p. 15.

1888, gives the results of one year's observations, from July 1, 1887, to June 30, 1888, of the Piche evaporometer.

From this article are obtained the following figures, which give the computed evaporation in inches at several points:

Estimated depth of evaporation in inches.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.
Salt Lake, Utah	1.8	2.7	3.6	7.2	6.9	8.9	9.2
Boise City, Idaho	1.6	2.5	3.8	6.1	6.5	6.6	10.0
Winnemucca, Nev	0.9	2.8	6.2	9.1	9.3	10.1	11.5
Denver, Colo	2.8	3.7	3.5	7.6	5.8	10.5	8.3
Cheyenne, Wyo	3.3	5.7	4.0	8.2	5.2	10.4	8.0
Helena, Mont	1.1	3.6	2.1	6.1	4.3	5.5	7.2
Santa Fe, N. Mex	3.0	3.4	4.2	6.8	8.8	12.9	9.2
Yuma, Ariz	4.4	5.2	6.6	9.6	9.6	12.6	11 0

Station.	Aug.	Sept.	Oct.	Nov.	Dec.	12 mos. evaporation.	Precipitation in 1888.
Salt Lake, Utah	10.7	9.6	6.5	5.0	2.3	74.4	13.62
Boise City, Idaho	9.2	7.4	5.2	3.2	1.8	63.9	11.09
Winnemucca, Nev	12.0	9.9	6.6	3.7	1.8	83.9	4.89
Denver, Colo	8.5	6.1	4.9	4.2	3.1	69.0	9.51
Cheyenne, Wyo	7.7	8.6	5.8	6.1	3.5	76.5	14.51
Helena, Mont	7.7	6.4	4.3	3.0	2.1	53.4	10.14
Santa Fe, N. Mex	9.8	6.6	6.7	5.7	2.7	79.8	12.03
Yuma, Ariz	10.2	8.2	8.2	5.5	4.6	95.7	2.95

An estimate of the total amount of yearly evaporation from water surfaces in this State, based on the foregoing facts, would vary from 3 to 6 feet in depth, depending upon the temperature, frequency, and velocity of the winds, dryness of the atmosphere, and like conditions. From the same data we may conclude that, generally speaking, the evaporation during the four months of May, June, July, and August, or, in other words, the irrigation period of this section, is equal to that of the remaining eight months.

The comparatively large loss by the yearly evaporation from wet ground surfaces of the Western States is of far greater importance than the evaporation which takes place at water surfaces, for the reason that, in a measure, it can be controlled by man. Such conservation of the obtainable water supply results in having available a balance which can be utilized in reclaiming desert land and in increasing the productions of land now cultivated.

One of the cheapest and most effective methods of checking excessive evaporation is cultivation. In this regard Utah irrigators have an important lesson yet to learn. The custom of the majority is to apply large quantities of water to growing crops, making a paste of the top soil. In less than twenty-four hours the water in this top layer is evaporated, leaving the ground hard and baked. Under such

conditions it is astonishing how rapidly the soil moisture is evaporated. If this top crust is left undisturbed for a few days, the soil becomes parched, the crops apparently suffer for lack of moisture, and the unskilled irrigator fancies the only remedy is to apply more water.

With the most careful attention while irrigating, it is not possible always to prevent the formation of paste by the mixture of fine soil and water and the subsequent baking; but the robbing the soil of its moisture through excessive evaporation can be avoided by breaking up the surface crust as soon as it forms and by keeping the surface layer thoroughly pulverized, thus effectively checking evaporation in even the hottest weather.

Recent experiments have shown that evaporation from the surface of soil can be greatly decreased by mulching. The effect, for example, of a 3-inch layer of broken, compacted oat straw, spread evenly over the surface of a strawberry field in Minnesota, was to decrease the evaporation by 605 barrels per acre, and the gain in moisture to the soil of a vineyard by a similar treatment was 1,600 barrels per acre, sufficient to cover the entire surface to a depth of nearly 2 inches.[1]

It has been repeatedly demonstrated that wind is a prime factor in increasing evaporation from both ground and water surfaces. While it is true that the frequency, course, and velocity of the winds lie beyond the control of the agriculturist, yet by planting suitable trees to form wind-breaks within and around cultivated fields, much benefit may be gained. The foliage of the trees will decrease the temperature, increase the humidity of the air, and break the force of the wind.

Perhaps the most complete test of the amount of water evaporated from soil and water surfaces was made in England by Charles Greaves,[2] M. Inst. Civ. Eng. His results are summarized by Fanning as follows:

> The mean annual rainfall during the time (1860 to 1873) was 27.7 inches. The annual evaporations from soil were—minimum, 12.07 inches; maximum, 25.14 inches, and mean, 19.53 inches; from sand—minimum, 1.43 inches; maximum, 9.10 inches, and mean, 4.65 inches; from water—minimum, 17.33 inches; maximum, 26.93 inches, and mean, 22.2 inches.[3] The climatic conditions of arid America are so unlike those of England that the above results do not in the least apply. They show, however, that, other conditions being equal, the amount of evaporation from ground surfaces is somewhat less than from water surfaces.

Dr. E. Wollny of Munich confirms this view when, in summarizing the work of three years on evaporation from land surfaces, he concludes:[4]

> (1) That the quantity of moisture evaporated from the soil into the atmosphere is considerably smaller than that evaporated from a free surface of water.

[1] Bulletin No. 32, Minnesota Agricultural Experiment Station.
[2] Trans. Inst. Civ. Eng., Vol. XLV, pp. 3-29.
[3] A Treatise on Hydraulic and Water-Supply Engineering, by J. T. Fanning, 1889, p. 90.
[4] *Prof. E. Wollny*, Forschungen, Vol. XVIII, p. 486. Abstracted in the Monthly Weather *Review, Department of* Agriculture, November, 1895, p. 422.

(2) That the evaporation is smallest from naked sand, and largest from naked clay, whereas naked turf and humus or vegetable mold have a medium value.

(3) That the evaporation is increased to a considerable extent by covering the ground with living plants.

(4) Evaporation is a process that depends upon both the meteorological conditions and on the quantity of moisture contained by the substratum of soil.

(5) Among the external circumstances, temperature is of the greatest importance, inasmuch as, in general, evaporation increases and diminishes with it; but this effect is modified according as the remaining factors come into play and in proportion to the quantity of water supplied by the substratum.

(6) The influence of higher temperature is diminished more or less by higher relative humidity, greater cloudiness, feebler motion of the wind, and a diminished quantity of moisture within the soil, whereas its influence increases under opposite conditions.

On the other hand, low temperatures can bring about greater effects than high temperatures, if the air is dry, or the cloudiness small, or the wind very strong, or if a greater quantity of water is present within the evaporating substance.

(7) For the evaporation of a free surface of water, or for earth that is completely saturated with water, the important elements are, first, the temperature; next, the relative humidity of the air, and then the cloudiness and the direction and velocity of the wind; whereas, for the ordinary moist earth, no matter whether the surface is naked or covered with living plants, it is the quantity of rain upon which the soil depends for its moisture that is the important additional consideration. The effects of the external elements on evaporation become less important, as explained in paragraph 5, in proportion as the precipitation is less and as the soil is more completely dried out by the previous favorable weather, and vice versa. For these reasons the rate of evaporation from a free surface of water not infrequently differs largely from that from the respective kinds of soil.

(8) Free surfaces of water and soils that are continuously saturated evaporate into the atmosphere on the average more water under otherwise similar circumstances than soils whether naked or covered with plants and whether watered artificially or naturally. Only at special times, viz, when the influence of the factors that favor evaporation is most intense, when the plants are in the most active period of growth, and when the soil contains a large percentage of water, can the land that is covered with plants show larger evaporating power than the free water surface.

(9) When a soil that is not irrigated is covered with plants, it evaporates a far greater quantity of moisture than when the surface is bare. In the former case the evaporation can not exceed the quantity received by the soil from the atmosphere before or during the period of growth. Swampy lands and those that are well irrigated, as also free surfaces of water, can, under circumstances favorable to evaporation, sometimes give to the atmosphere a greater quantity of water than corresponds to the precipitation that occurs during the same time.

(10) The evaporating power of the soil is, in itself, dependent upon its own physical properties; the less its permeability for water, or the larger its capacity for water and the easier it is able to restore by capillarity the moisture that has been lost, by so much the more intensive is the evaporation. For this reason the quantity evaporated increases with the percentage of clay and humus in the soil, whereas it diminishes in proportion as the soil is richer in sandy and coarse-grained materials.

(11) Soil that is covered with plants loses by evaporation so much more water in proportion as the plants are better developed, or stand thicker together, or have a longer period of vegetation, and vice versa.

In the above summary Dr. Wollny touches upon various phases of evaporation which have an important bearing on Western irrigation. At present there is little data to enable us to compare intelligently the results obtained in Germany with those in this country. However, some of the Agricultural Experiment Stations are taking up this work, and in a few years we may hope to know much more of the behavior of soil moisture and ground waters and their relation to plant life. The main object to be attained in the artificial application of water to soil is to develop plant life, and as this can be accomplished only by creating a moist soil and subsoil, it is necessary that we endeavor to ascertain the greatest possible percentage of the total precipitation that can be used for this purpose. In this State evaporation from both water and land surfaces must be regarded as one of the chief sources of waste, and as such deserving of careful study.

TRANSPIRATION.

In arid America agricultural products are almost entirely dependent upon the water supply. As a rule, the soil is fertile, containing in abundance the elements necessary for the development of plants; but if the water supply be either deficient or applied at the wrong time, a partial growth will result. The portions of a wheat field that are missed at the first irrigation seldom yield one-third of a crop. These dry places may be irrigated subsequently, but the second watering can not restore the shrunken cellular tissues nor the lost vigor. The skilled horticulturist has learned by experience and observation how and when to irrigate his fruit trees. When the trees are young, water is conveyed in two furrows only, one on each side the row of trees and at some little distance beyond the farthest roots. As the tree grows, the roots thrust themselves farther into the soil, but chiefly in the direction of the water supply, and in the following season the two furrows may be increased to four, until finally, in well-matured trees, all the space of 20 feet or more between the rows is thoroughly watered. By such a method water is not only provided for the soil, but is applied in such a way as to lead out the roots in quest of moisture and food.

Much has been written recently on subirrigation, and many agricultural experiment stations have gone so far as to pronounce this method superior to all others. By it water is conveyed through pipes buried in the ground and is discharged through a large number of small holes located opposite each tree. This mode of irrigation has not been successful. In the first place, it is an impossibility to cause water to discharge equally through so many orifices; and in the second place, the water is deposited at particular points in the soil, around which the roots of plants are sooner or later massed. The few advantages to be gained by applying the water beneath the sur-

face can not be compared to the disadvantages due to the difficulties in the way of its distribution and to the concentration of the roots at particular places.

The injurious effects upon vegetation caused by either too little water or too much are clearly illustrated by the results of experiments made by Dr. E. Wollny[1] on summer rape, as given in the following table. In this, the first column gives the per cent of water in the soil as compared to the total water-holding capacity. The second column gives the number of pods produced, and the following columns give the weight of the various parts:

Effect of excess and deficiency of moisture.

Per cent of water in the soil.	Number of pods.	Weight of plants air dried			
		Seed, in grams.	Straw, in grams.	Chaff, in grams.	Total, in grams.
10	48	1.4	2.8	1.4	5.6
20	61	2.4	4.4	2.6	9.7
40	142	6.9	10.4	6.7	24.0
60	97	4.3	8.1	4.4	16.8
80	95	3.9	7.3	3.9	15.1
100	19	0.3	2.0	0.6	2.9

In growing plants in pots it is possible to apply just the right amount of moisture, but on the irrigated field it is somewhat different. At each watering the ground is for a time nearly saturated. Part of this excess water is soon evaporated, either from the ground or indirectly through the foliage. Another part sinks into the subsoil, and the remainder keeps the soil moist. If this soil moisture can be maintained in the right proportion, or, in other words, if the amount drawn from the subsoil by capillarity equals the loss by evaporation until the next watering, the crop will grow under the most favorable conditions as regards moisture. If too little water is applied to the surface and the subsoil water for some cause is inaccessible, the crop will suffer and become more or less dwarfed. On the other hand, too much water may keep the soil near the extreme of complete saturation and produce upon vegetation as harmful effects as too dry a soil. A cubic foot of average soil when thoroughly saturated will contain from 25 to 30 pounds of water. According to Wollny's experiment, the best results were obtained on summer rape when about 40 per cent of the empty space in the soil was filled, which would be equivalent to from 10 to 12 pounds of water in every cubic foot of soil.

We may thus classify productive soils under three heads in relation

[1] Experiment Station Record, Vol. IV, p. 532.

to the percentage of moisture which each contains, viz, as dry soils, moist soils, and wet soils. It may also be said that in each of these classes the amount of water drawn up by the roots and transpired by the leaves differs. The magnitude of this transpiration of vapor through the foliage of plants has been investigated by Messrs. King, Wollny, Hellriegel, and others, the results of whose labors are briefly summarized in the following tables:

Amount of water required for a pound of dry matter in Wisconsin.[1]

Crop.	Year.	Water per pound of dry matter.	Yield per acre, pounds.	Water per acre, inches.
Barley	1891	402	7,441	13
Do	1892	375	14,196	23
Oats	1891	501	8,861	20
Do	1892	525	8,189	19
Corn	1891	301	19,845	26
Do	1892	316	19,184	25
Clover	1892	564	12,486	30
Pease	1892	477	8,017	17

Ratio of water evaporated to weight of crop harvested, as shown by experiments of Hellriegel and Wollny.[2]

Crop (Hellriegel).	Water evaporated.	Crop (Wollny).	Water evaporated.
Horse beans	262	Maize	233
Pease	292	Millet	416
Barley	310	Pease	447
Clover	330	Sunflower	490
Spring wheat	359	Buckwheat	646
Buckwheat	371	Oats	665
Lupine	373	Barley	774
Spring rye	377	Mustard	843
Oats	402	Rape	912

According to Hellriegel, as shown by the above table, 330 tons of water would be absorbed by the roots of clover, drawn up through the stems, and evaporated from the breathing pores of the leaves, for each ton of clover harvested. If the yield be estimated at 3 tons per acre, the quantity of water per acre is 990 tons, or a volume sufficient to cover the surface to a depth of nearly 9 inches. So far as has been ascertained, no tests have been made in the Rocky Mountain region

[1] F. H. King, Agricultural Experiment Station, University of Wisconsin, Ninth Annual Report. 1892, p. 94.

[2] *Department of Agriculture*, Experiment Station Record, Vol. IV, p. 532.

of the amount of water actually consumed by the various agricultural crops between the time of germination and the harvest, but observed facts seem to indicate that this amount varies with the conditions of soil moisture.

In sections of northern Utah, where water can not be readily or cheaply conveyed to irrigate the land, the fields are usually sown in wheat and cultivated "dry," the annual yield being from 12 to 25 bushels per acre. During the period of growth the rainfall is occasionally less than 1 inch, and the soil and subsoil apparently are very dry. If the quantity of water consumed by the wheat was even one-third of that given by Prof. F. H. King for barley and oats, which averaged a depth of nearly 19 inches over the entire surface cultivated, it is difficult to conjecture where the supply could come from.

On irrigated lands the case is quite different. The proper amount of moisture is maintained in the soil, the plant is kept in a healthy, vigorous condition, and the normal amount of water passes through its tissues, bearing the necessary mineral food furnished by the soil. It is not unusual to irrigate alfalfa every other week, and to spread an amount of water over the surface during its period of growth sufficient to cover the ground to a depth of 6 feet. A part of the water used in irrigating usually sinks into the subsoil and flows off as seepage water, a second part is evaporated, and the third part, possibly one-third of the whole supply, passes through the tissues of the plant and is mostly transformed into vapor at the leaves.

The sagebrush and grasses indigenous to the uncultivated lands of the Rocky Mountain region require but little moisture to maintain their slow growth. In the vicinity of Corinne, Boxelder County, Utah, the average annual rainfall for the past twenty-five years has been less than 12 (11.73) inches. Little snow remains for any length of time on the ground; the evaporation in summer is excessive on all moist ground and water surfaces; and yet sagebrush flourishes, growing to a height of from 3 to 5 feet. If we deduct from the total yearly precipitation the probable amount of moisture evaporated, very little will remain for the use of the plants. It is possible that the total quantity of water absorbed by the roots of the plants that grow on uncultivated lands and transpired by their foliage does not exceed one-tenth of the annual precipitation, which in this State would be about 1¼ inches over the surface of unreclaimed arable lands. On the preceding estimates, based on observed facts, we may therefore conclude that in this State the amount of water evaporated from the foliage of plants ranges from a surface depth of 1 inch for buffalo grass and sagebrush to a surface depth of 20 inches for well-irrigated alfalfa.

CACHE VALLEY.

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CACHE VALLEY.

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same range forms the lower divide between it and Great Salt Lake and Malad River valleys to the west. The average elevation of the cultivated portion of the valley is about 4,500 feet. Its length from north to south varies from 40 to 50 miles, and its width from east to west from 10 to 15 miles.

The first white men who wintered in the valley were the Garr brothers. They were engaged by the authorities of the Mormon Church during the winter of 1855–56 to look after the range cattle owned by that church, and they built a rude log hut in the vicinity of what is now the church farm. In the summer of 1858 several families from Brigham reached the valley through Boxelder Canyon and made a permanent settlement in what is now Wellsville.

According to the latest report of the Utah statistician, the population of Cache County in March of 1895 was 18,286. The principal towns and cities in the order of population are: Hyde Park, 647 inhabitants; Providence, 944; Lewiston, 969; Richmond, 1,295; Wellsville, 1,390; Smithfield, 1,448; Logan, 5,756; total, 14,249.

Cache County contains an area of 697,600 acres, of which 30,923[1] acres were irrigated in 1889, and 38,430[2] acres in 1894. From information collected during the past season, supplemented by the records obtained by C. D. W. Fullmer, county statistician, the following table has been prepared, giving the approximate number of acres irrigated for each kind of crop in 1896.

Approximate area irrigated in 1896.

	Acres.
Cereals	20,000
Lucern, hay, etc	15,000
Potatoes, beets, etc	1,500
Fruit trees	1,200
Small fruits	25
Other products	900
Total	38,625

The water utilized in irrigating the southern end of the valley is diverted chiefly from New Canyon, Little Bear, and Blacksmith Fork streams. Logan River, with Summit, High, and Clarkson creeks, furnish the supply for the middle portion. Cub and Weston creeks are the chief sources of supply for the northern portion. Surveys for irrigating canals have been made to divert water from Bear River, in Cache Valley, but owing to the lengths of the proposed canals and the cost of construction, none has yet been built.

The soil in the cultivated portions of the southern end of the valley, and particularly in the vicinity of the towns of Paradise, Hyrum, and Millville, consists for the most part of a rich, black, clayey loam. In the western part clay, with occasional patches of alkali, predominates.

[1] Eleventh Census, Agriculture by Irrigation, F. H. Newell.
[2] *First* Triennial Report of the Bureau of Statistics of Utah.

The soil in the northern and northwestern portion of the valley varies from coarse gravel to fine sand and clay. On the whole, it may be designated as a soil well adapted for the production of wheat.

LOGAN RIVER.

The greater part of the drainage basin of Logan River lies in the mountain range east of Cache Valley. The main source of the stream is quite small, and heads high on the range about 40 miles within the mountains; but as it flows down a steep channel toward the west its

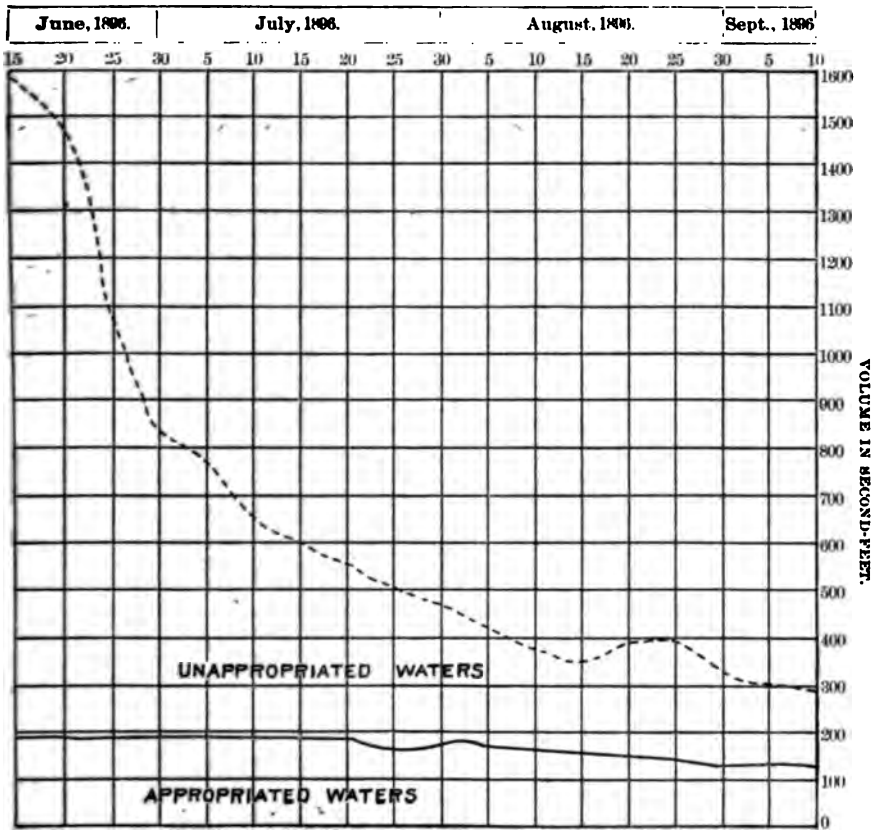


FIG. 4.—Diagram showing appropriated and unappropriated waters of Logan River.

waters mingle with those from Temple Fork, Boss Canyon Creek, Spring Creek, Ricks Spring, and Right Hand Fork Creek, which, when united, form one of the most important rivers in the State. From its head waters to where it unites with Bear River is some 50 miles, only 10 of which lie outside rugged canyons.

About the 1st of June, 1896, a permanent gaging station was established on this river a short distance below the mouth of the canyon

and above all the canals save one, the Logan, Hyde Park and Smithfield. From daily river-height observations and several current meter measurements the flow has been accurately determined throughout the season. The waters used for beneficial purposes have also been determined by a series of measurements of each canal, and both results are represented graphically in fig. 4. The aggregate volume of all the canals is nearly 200 second-feet; and as the discharge of the river at the mouth of Logan Canyon during a dry season may be less than that amount, the apparent large surplus of last summer, which averaged during the month of August, 1896, 222 second-feet, is not to be depended upon.

Irrigating canals diverting water from Logan River.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Logan, Hyde Park, and Smithfield Canal	12	34.5	21	47.5	31	30.1	....	.....
Logan and Richmond Canal	12	60.4	21	60.1	31	50.1	....	.....
Providence Canal	12	5.4	21	8.2	....	.....	1	5.2
Logan, Hyde Park, and Thatcher Canal	12	*a* 48.0	21	*27.0	31	27.5	....	.....
Nursery Canal	....	.....	21	2.4	....	.....	1	0.7
Logan and Benson Ward Canal	12	*a* 25.0	21	23.9	....	.....	1	19.3
West Field or Little Ditch	....	.....	21	11.6	....	.....	1	7.5

a Estimated.

The Logan, Hyde Park, and Smithfield Canal was completed in June, 1882. Its head gate is located about 1½ miles above the mouth of the canyon, and at an elevation of 326 feet above the business center of Logan City. In July, 1892, the writer, as the consulting engineer of the city corporation, advised the abandonment of the old source of supply, and recommended that the future source be the Logan, Hyde Park, and Smithfield Canal, until funds were available to extend the conduit to the river. Logan City now gets its domestic water supply from that canal, and owns 26⅔ per cent of its paid-up capital stock. The canyon portion of the canal was never properly constructed, and the loss through leakage is very great. On August 31, 1893, the discharge at the head gates, as measured by the writer, was 48 second-feet. At a point 7,000 feet lower down the volume had been decreased, on account of waste, to 26.7 second-feet, a loss of 21.3 second-feet, or 44 per cent of the volume diverted. The area irrigated since 1892 has not varied to any appreciable extent, and the following table gives the figures for the three preceding years:

Area irrigated by Logan, Hyde Park, and Smithfield Canal.

Year.	Farm lands.	City lots	Total.
	Acres.	*Number.*	*Acres.*
1890	2,184	*a* 63	2,310
1891	2,409	163	2,735
1892	2,785	169	3,123

a A city lot is equivalent to 2 acres of farm land.

The Logan and Richmond Irrigating Company was organized in November, 1864, and the canal was built in 1865–1867. The records of the company show that the land irrigated by this canal in 1878 was 1,400 acres of farm lands and 195 city lots, but the capacity of the canal was considerably increased in 1881, and more land was reclaimed at its lower terminus in the vicinity of the town of Smithfield. The areas irrigated by this canal in 1895 are as given below:

Area irrigated by Logan and Richmond Canal.

Precinct.	Farm lands.	City lots.	Total.
	Acres.	*Number.*	*Acres.*
Logan	897	214	1,325
Hyde Park	610	50	711
Smithfield	1,240	0	1,239
Total	2,747	264	3,275

Providence Canal is the only irrigating system of any considerable size which diverts water from the south or left bank of Logan River. It was begun in 1866, but owing to the fact that the locating engineer set pegs on an ascending grade from the proposed place of diversion, and the water would not flow uphill, the enterprise was abandoned until 1883, when the necessary changes in the elevations were made and the canal completed. The cost of maintenance has always been high, owing to faulty location and steep hillsides, averaging about $250 per annum, and the area irrigated since 1883 has not varied far from 300 acres.

Logan, Hyde Park, and Thatcher Canal was begun in the spring of 1860. It is the oldest in Cache Valley, and was the first to divert water from Bear River or its tributaries. The primary object held in view by the original projectors was to irrigate wheat lands, but several mill owners obtained permission to widen the canal sufficiently to furnish them with a supply for power purposes. A portion of the flow has been so employed ever since, but the tail water from the mills

is nearly all subsequently used in irrigation. The canal branches at Sixth street, the upper branch extending to Hyde Park, the lower to a portion of Logan City. The acreage irrigated in 1860 was about 700 acres, and there has been a nearly uniform increase from that time to the present. Of late years the total number of acres irrigated by both branches of the canal has averaged about 2,115, of which 1,215 acres are located in Hyde Park and the remainder in Logan.

Logan and Benson Ward Canal has its headgates near the business center of Logan. The date of its water appropriation extends back to 1861. The extent of land at present irrigated by this canal includes 856 acres in Benson Ward and 2,150 acres in Logan precinct.

West Field, or Little Ditch, takes its supply from the tailraces of the mills and from Logan River at the city park. The first branch was made in the spring of 1860. The ditch flows into Spring Creek pond and receives a portion of its supply from this last source. The area irrigated in late years is 1,100 acres.

The average combined capacity of the 6 canals enumerated above was, for June, 1896, 188.8 second-feet; for July, 183.3 second-feet; for August, 157.6 second-feet; and for September, 131.5 second-feet. Comparing this with the aggregate area irrigated—12,920 acres—it appears that the duty of water per second-foot in June was 68.4 acres; in July, 70.4 acres; in August, 81.9 acres; and in September, 98.3 acres.

BLACKSMITH FORK RIVER.

This stream rises in a range of the Wasatch Mountains which separates Cache Valley from Rich County, flows in a northwesterly direction, and empties into Logan River. Its total length is about 35 miles. The average depth of compacted snow near the sources of this stream in February and March is about 4½ feet, and as the greater part of this snow melts during the month of May and the early part of June, the spring floods are excessive in proportion to the comparatively small area drained.

The discharge of this stream at a point a short distance below the mouth of Blacksmith Fork Canyon from June 15 to September 15, 1896, and the combined flow of all the irrigating canals diverting water therefrom are represented graphically in fig 5. The maximum volume of water appropriated and utilized is therein shown to be 180 second-feet, while the discharge of the stream may be said, if we except a few days in September, not to fall below that amount during the irrigating period.

As shown by the following table, six canals divert water from this source and vary in carrying capacity from 4 to 70 second-feet. The Hyrum Canal is the largest and is divided near its head gates, the upper branch supplying water to a portion of Hyrum City, and the *lower being* used on the fields adjacent to Millville. Solveson & Co.'s

itch is one of small capacity, and waters the lands on the river bot-oms. The remaining four canals extend to the town of Millville and s vicinity, two being taken out on the east side of the river and two 1 the west.

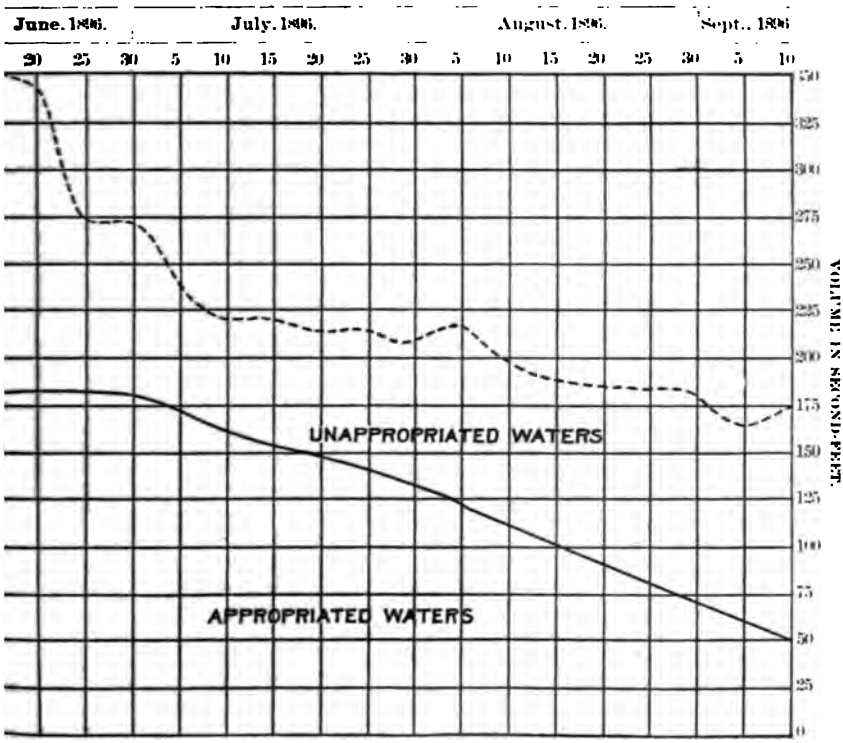


FIG. 5.—Diagram showing appropriated and unappropriated waters of Blacksmith Fork River.

Irrigating canals diverting water from Blacksmith Fork River.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Solverson & Co.'s ditch	18	3.9	9	0.8	5	2.2	15	Dry.
No. 1 canal	18 29	27.8 32.9	10	17.4	4	22.8	15	4.3
Hyrum canal	18	48.7	10	63.6	4	65.9	15	22.8
No. 3 canal	18	70.6	10	51.7	4	26.1	15	11.2
No. 2 canal	..	.....	9	16.4	4	6.7	15	3.4
No. 4 canal	.....	.....	9	13.5	4	1.1	15	Dry.

LITTLE BEAR RIVER.

Little Bear River, Little Muddy River, or Boxelder Creek, as it is variously termed, is a tributary of Logan River. It is formed by two main streams which unite near the town of Paradise, in the southern

part of the valley. One of these tributaries is called the East Fork of Little Bear River, and has a total length from its head waters to its mouth in Logan River of 33 miles. The general trend of its course within the mountains is easterly, but after joining the South Fork the

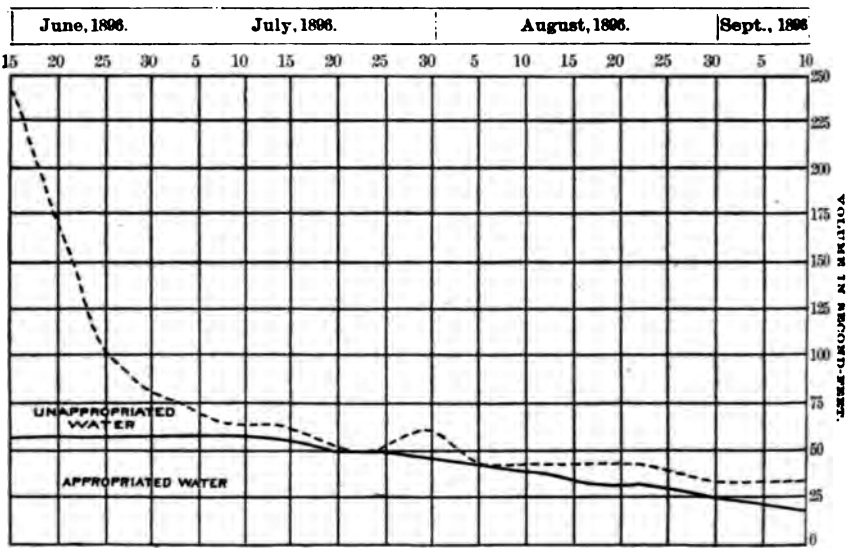


FIG. 6.—Diagram showing appropriated and unappropriated waters of South Fork of Little Bear River.

combined waters flow in a northerly direction to Logan River. The South Fork is fed by numerous springs and rivulets which flow from the south side of the divide lying between Cache Valley and Ogden Valley, and its greatest length from its source to its confluence with the East Fork is 10 miles. The following table gives the names and

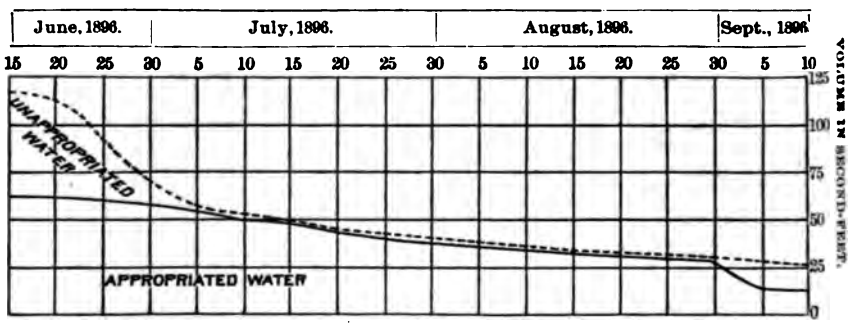


FIG. 7.—Diagram showing appropriated and unappropriated waters of East Fork of Little Bear River.

the capacities at stated periods of each ditch or canal diverting water from Little Bear River and its tributaries. A glance at figs. 6 and 7 *shows that the* waters of both forks were nearly all utilized during *the past season.*

In this portion of the valley the gain due to seepage waters from irrigated areas and from the adjacent bench lands is of considerable value to the inhabitants of Wellsville. On July 15, 1896, the flow in the South Fork was 61 second-feet. On the same date Hyrum canal was diverting 55 second-feet, and a surplus of 24 second-feet remained in the river. These figures show a gain from seepage and deep-seated springs of 43 second-feet. Subsequently the springs were measured and aggregated nearly 20 second-feet, thus leaving a balance of 23 second-feet of seepage waters.

Irrigating canals diverting water from Little Bear River.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
From East Fork.								
Jackson Surplus Ditch	19	3	10	2.3	6	Dry.	....	.....
Frank Law Ditch	19	1.6	10	Dry.	....	.....	....	.....
Facer Ditch	19	6.8	10	1.1	6	Dry.	....	.....
Paradise Irrigation and Reservoir Company's Canal	19	50.2	10	47.2	6	35.1	15	22.5
From South Fork.								
Nichols Ditch	....	.....	11	Dry.	....	.....	....	.....
Davis & Co.'s Ditch	....	.....	11	Dry.	....	.....	....	.....
Hyrum Canal	....	.....	11	57.4	6	40.1	15	12.8
From main stream.								
South Field Ditch	....	.....	11	2.7	6	Dry.	....	.....
Paradise Hollow Ditch	....	.....	14	2.5	7	2	15	Dry.
Miller Ditch	....	.....	14	2.8	7	1.4	15	Dry.
Wellsville East Field Ditch	....	.....	14	26.1	7	4.9	12	2.6

CUB RIVER.

Cub River, the main source of supply for the northern portion of Cache Valley, rises in Idaho, flows in a southwesterly direction for a distance of 28 miles, and empties into Bear River. The six ditches which head on this stream were each measured three times last summer, with results as stated in the following table. The highest is the Cub River and Worm Creek Irrigation Company's canal, which supplies with water the town of Preston, Idaho. It is taken out on the north side of the river, and conveyed through a pass in the ridge into Worm Creek channel, which is used to convey the canal water to a lower elevation, where it is again diverted into several ditches that distribute irrigating water to the various precincts of Preston. The next canal of any considerable importance is that of the Cub River and Middle Ditch Irrigation Company, which on June 25 carried *50.7 second-feet.* By far the largest canal on this stream

was begun in 1860, for the purpose of watering bench lands located north of Franklin, on the right bank of Cub River. Owing, however, to a grave error in the grade, the project was temporarily abandoned, and it was not until after the settlement of Lewiston that a resurvey was made and the canal completed. It is now known as the Lewiston Ditch, or canal. The lowest canal, but the first to divert water from Cub River, if one excepts the Perkins Ditch, which is now practically abandoned, is the Franklin City Ditch, which was built in 1864 by Messrs. Parkinson, Smart, Woodward, and others.

The accompanying diagram (fig. 8) showing the appropriated and unappropriated waters of Cub River, indicates a large surplus during the months of June, but after July 10 the flow is nearly all utilized by the various canals.

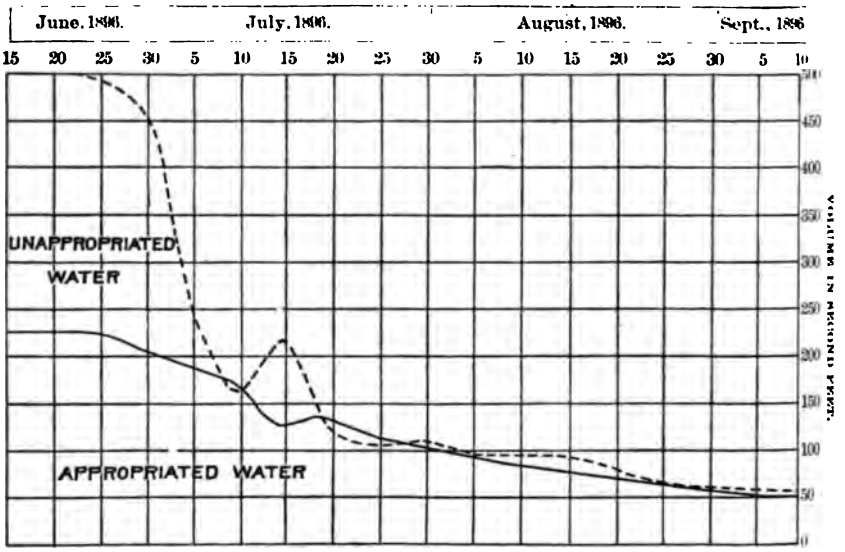


FIG. 8.—Diagram showing appropriated and unappropriated waters of Cub River.

Irrigating canals diverting water from Cub River in Oneida County, Idaho.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Cub River and Worm Creek Irrigation Company's canal	25	42.5	27	31.8			7	8.4
Morehead, Taylor, and Kent Ditch	25	4.8	26	1.5			7	Dry.
Cub River and Middle Ditch Irrigation Company's canal	25	50.7	27	15.9			7	12.0
Taylor ditch	25	Dry.	27	2.1			7	Dry.
Lewiston ditch	25	122.1	27	51.0			7	30.2
Franklin City ditch	26	5.6	28	2.4			7	Dry.

HIGH CREEK.

High Creek is a tributary of Cub River. It rises near the boundary line between Utah and Idaho and flows in a southwest course for a distance of about 9 miles. Numerous ditches, as may be seen by the following table, take water from this comparatively small stream, but, with the exception of the two Richmond canals, their discharges during July and August are small. The Richmond Irrigation Canal, increased by a portion of the flow from Cherry Creek, waters the sloping bench lands lying between High Creek and Richmond. This canal, when augmented by the flow from City Creek, also furnishes water for the upper portion of the town of Richmond. The lower portion of this town and the farm lands adjacent thereto are watered by the Richmond City Canal.

Irrigating canals diverting water from High Creek, in Cache County, Utah.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Williams and Derney Ditch	28	1.3	29	Dry.				
Upper High Bair Ditch	28	2.9	29	Dry.				
Upper Coveville Ditch	28	7.8	29	Dry.				
Richmond Irrigation Company's Canal	28	43.2	29	2.5			9	1.0
Williams Bros., Eckelson and Day Ditch	28	3.6	29	Dry				
Norman Day Ditch	28	0.7	29	Dry.				
Richmond City or Irrigation Canal	28	25.5	29	16.4			9	3.8
Two Eleventh Ditch	28	8.7	29	0.9			9	1.0
Lower Coveville Ditch	28	6.8	29	1.2			9	2.1
J. Bright Ditch	28	8.9	29	2.8			9	0.6

SUMMIT CREEK.

Summit Creek has its source near the head waters of Logan River, and after flowing in a southwesterly course for a distance of 13 miles empties into Bear River. The summer flow of this creek is diverted through various canals, a list of which is given in the order of elevation in the following table, and is used to irrigate the town lots of Smithfield and the farm lands adjacent thereto. A portion of the flow is first used for mechanical purposes, but is subsequently diverted for irrigation purposes.

Irrigating canals diverting water from Summit and Birch creeks in Cache County, Utah.

Name of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Roskelly Ditch			3	Dry.				
Peterson Ditch			3	Dry.				
Surplus Ditch			3	13.0			10	2.8
			31	3.9				
Union Milling Company's Ditch			3	3.6			10	0.8
			31	1.1				
Mack's Old Mill Race Ditch			3	14.1			10	3.1
			31	5.0				
City Ditch			3	1.0			10	0.2
			31	0.3				
Morehead Ditch			3	0.7			10	0.1
			31	0.2				
Levy Ditch			3	11.9			10	1.6
			31	3.6				
Big Ditch			3	21.8			10	4.8
			31	6.7				

MISCELLANEOUS MEASUREMENTS.

wing table gives the results of measurements made of the als and ditches from other streams within Cache Valley those before described:

Results of measurements of irrigation canals and ditches.

of canal or ditch.	June.		July.		August.		September.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
Clarkston Creek.								
k ditch					12	3.6	3	3.0
ı ditch					12	1.9	3	1.4
ı ditch					12	1.5	3	2.0
Creek, Oneida County, Idaho.								
seler ditch			27	0.2			7	Dry.
Perkins ditch			27	0.9			7	0.4
seler ditch			27	0.9			7	Dry.
rry Creek, in Cache ounty, Utah.								
rry ditch	30	10.7	30	6.2			9	1.1
ek Water Section canal	30	7.5	30	0.9			9	1.0
Creek and tributaries, reek and Deep Canyon, County, Idaho.								
anyon Creek ditch	27	0.3	28	0.4			8	Dry.
on and J. Lowe ditch	27	2.7	28	Dry.				
ch	27	0.4	28	1.0			8	Dry.
t ditch	26	2.7	28	Dry.				
ek or Franklin City	26	11.6	28	5.0			8	3.1
l Woodward ditch	27	1.7	28	2.9			9	0.6
ditch	26	3.5	28	Dry.				
l Flack ditch	26	4.6	28	1.7			8	Dry.
g Creek, at Providence, he County, Utah.								
ch			8	0.7	3	1.3	14	0.4
			8	2.2	3	3.9	14	Dry.
h ditch			8	10.6	3	11.7	14	4.2
h			8	9.5	3	3.5	14	6.8
			8	6.7	3	3.4	14	2.9
ation ditch			8	0.9	3	Dry.	14	0.2
ston Creek, in Oneida unty, Idaho.								
d Norton and Coburn			18	2.6	11	1.4	4	0.8
			18	3.6	11	1.5	3	1.6
litch			18	2.3	11	1.8	3	1.4
wn ditch			18	2.4	11	1.4	3	2.1
			17	2.5	11	1.0	4	1.0
l ditch			17	4.3	11	3.9	4	3.0

Smaller creeks and springs of Cache Valley from which water is diverted for irrigating purposes.

Name.	June.		July.		August.		September.		October.	
	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.
City Creek (Richmond)			1	2.6	1	Dry.				
City Creek (Clarkston)			17	0.9	12	0.8	3	0.7		
Deep Canyon Creek (Mendon)			16	1.4	12	1.5	11	1.2		
Dry Canyon Creek (Avon)					5	0.8	15	Dry.		
Dry Creek (Weston)			18	0.5			15	Dry.		
Flat Canyon Creek	27	0.9	28	Dry.						
Green Canyon Creek	13	5.9	31	Dry.						
Hyrum Dry Canyon Creek					6	0.4	15	Dry.		
Millville Creek			9	3.9	4	4.3	14	4.5		
Myler Creek			17	0.3	12	0.4	3	0.4		
New Canyon Creek			15	4.5	8	4.9	12	4.5		
Nebo Creek			1	0.6	30	Dry.				
Ox Killer Creek	27	0.4	28	Dry.						
Pole Canyon Creek					6	1.5				
Spring Creek (Richmond)	30	1.3	29	0.3			9	Dry.		
Three Mile Creek					12	0.1	11	Dry.		
Twin Creek			16	1.1	13	1.6	11	1.2		
Worm Creek	24	1.7	26	Dry.						
Coburn Spring							4	0.6		
Clayton Spring			15	1.8	8	1.9	12	1.6		
Done et al. springs									22	10.2
Gardner Spring			15	5.0	8	4.3	12	3.5		
Gibson et al. springs									22	6.5
Gitten Spring			16	0.4	13	0.5	12	0.4		
Garr Spring			9	3.6	5	3.2	14	3.1		
Graveyard Spring			16	0.6	13	0.5	11	0.4		
Hyrum Field Seepage springs					7	10.2				
Halverson Spring			30	0.5						
J. Stone and T. Lowe Spring	27	1.5					8	0.2		
Millville Creamery Spring							7	3.6		
Marks et al. springs									22	3.8
Michelson Spring							3	0.3		
Merrill et al. springs									22	5.9
New Dam Spring			15	4.0	8	4.3				
North Field Dam Spring No. 1			15	7.0	8	7.5				
North Field Dam Spring No. 2			15	4.0	8	3.6				
Pond Spring (Mendon)			16	1.1	12	0.9	11	1.1		
Pond Spring (Logan)							11	7.5		
Rocky Point Spring			16	1.6	12	0.5	11	0.3		
Wellsville City Spring			15	3.0						
Wm. Cunningham's Spring							12	0.15		
Wm. Hugh's Spring	26	0.17								
Newton Reservoir			17	8.6	12	4.9	2	1.9		
Hopkins's Slough									23	6.5

ces of water supply in Cache Valley not used in irrigation in Cache County.

Name of source.	June.		July		August.		September.		October	
	Date.	Discharge in sec. ft	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft.	Date.	Discharge in sec. ft	Date.	Discharge in sec. ft.
ır River at Battle										
'reek	23	3,954.1	25	1,187.2	....	....	5	872.6	....	....
Do	....	....	25	1,198.8	....	....	28	890.7	....	....
Do	....	....	25	1,197.9	....	....	....	....	....	....
ring Creek (Mendon)	....	....	....	....	....	....	....	....	20	66.4
ring Creek (Millville)	....	....	....	....	....	....	....	....	27	4.4
ring Creek (Franklin)	....	....	....	....	....	....	....	....	23	1.4

RESULTS OF STREAM MEASUREMENTS.

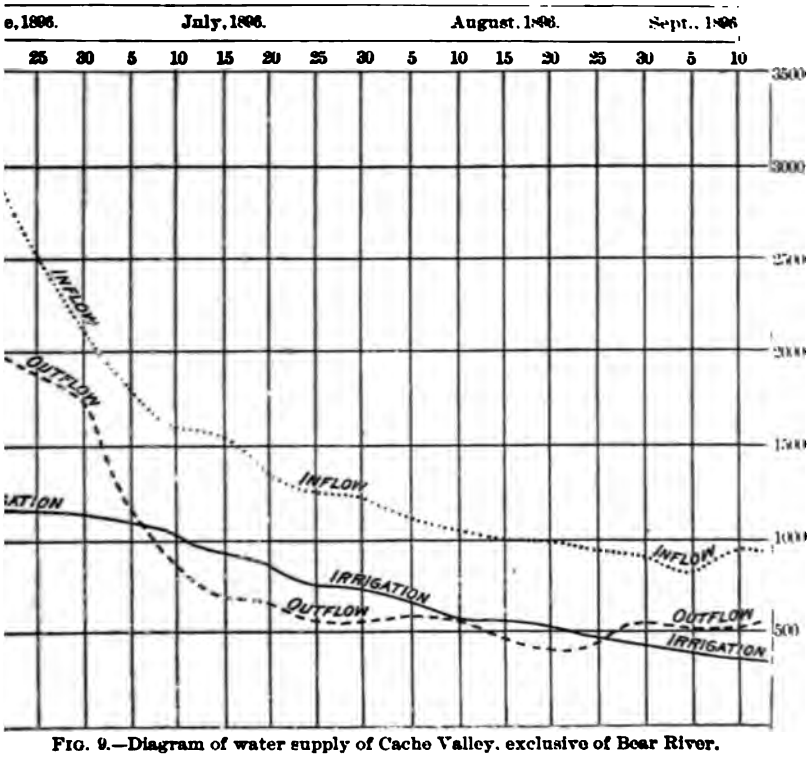


FIG. 9.—Diagram of water supply of Cache Valley, exclusive of Bear River.

'or purposes of comparison some of the results of the stream and al measurements made in Cache Valley during the summer of 1896 summarized in the diagrams of figs. 9 and 10. Fig. 9 shows the ow, outflow, and irrigating waters of the valley exclusive of Bear 'er, while fig. 10 includes both the inflow and outflow of Bear River. has been stated, no water is diverted from this river in Cache lley, *all the water* now utilized being obtained from the various

tributaries. The aggregate discharge of all these tributaries, including wells and springs, is shown by the curved line termed "inflow" in fig. 9. This diagram also shows the total amount of the inflow which was used for irrigation purposes and the surplus which was discharged into Bear River.

It will be seen that the volume used for irrigation on any one day does not represent the difference between the inflow and the outflow on the same day. On every day from June 15 to September 15, 1896,

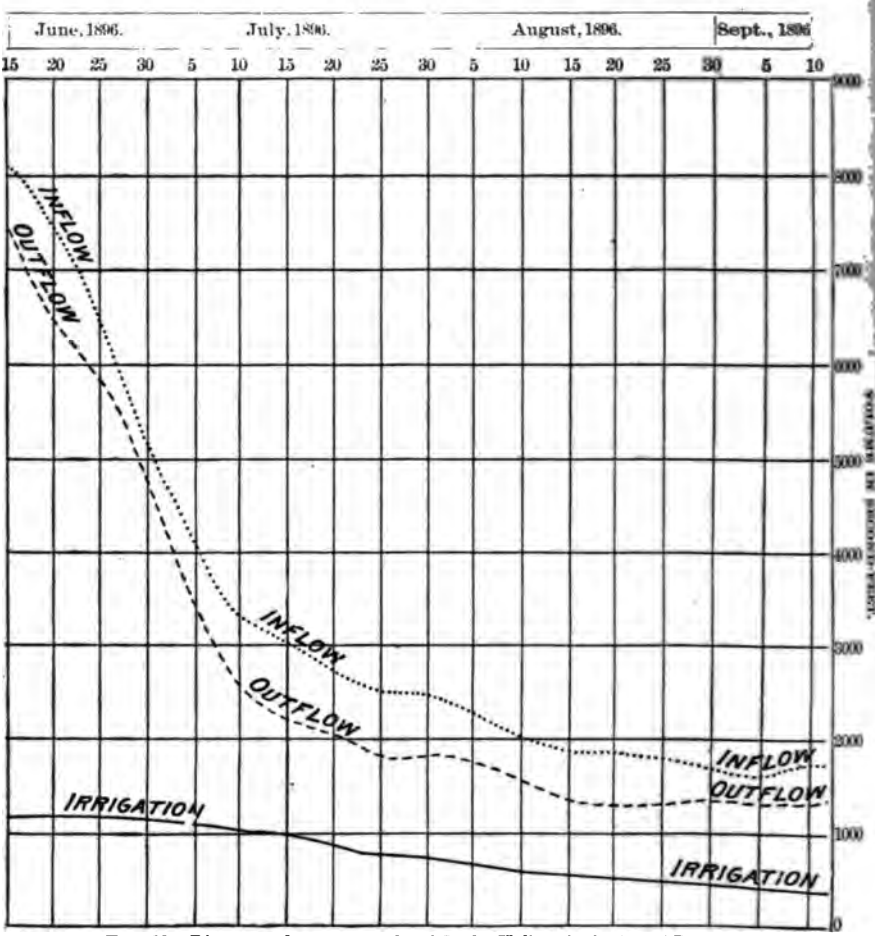


FIG. 10.—Diagram of water supply of Cache Valley, inclusive of Bear River.

excepting a few days in August, there was a gain due to seepage waters. This gain during the latter half of June averaged a continuous flow of 500 second-feet, or 18 per cent of the inflow, but it decreased rapidly until the 20th of August, when it began to increase gradually to September 15. In the following table are given, in cubic feet per second, the volume flowing into the valley, Bear River excepted,

volume diverted for irrigation, and the outflow, besides the average nthly gain, resulting from seepage waters.

Water supply of Cache Valley, exclusive of Bear River, in second-feet.

Date.	Inflow.	Irrigation	Outflow	Average monthly gain from seepage.
1896.				
June 15	3,275.8	1,163.1	2,659	
June 20	3,096	1,162.9	2,029	500.4
June 25	2,537.5	1,159 1	1,884	
June 30	2,107.6	1,136	1,739	
July 5	1,805.9	1,081.9	1,149	
July 10	1,591.4	1,020 2	849	
July 15	1,552.5	925 5	684	181 6
July 20	1,341.3	860	674	
July 25	1,244 2	755.6	554	
July 30	1,224 4	731 9	554	
August 5	1,108.2	632 2	557	
August 10	1,036.9	573.4	562	
August 15	998.6	547 5	462	34
August 20	997.7	512.3	417	
August 25	958.4	470.5	438	
August 30	905 2	442.8	553	
September 5	813.2	394.7	508	
September 10	938.9	352.7	508	61.5
September 15	884.6	334.7	003	

The rainfall from June 15 to September 15 on the 450 square miles ng within the area bounded by the locations of the stream meas- ments in Cache Valley was 3.58 inches, or an equivalent of 85,920 e-feet of water. Assuming, for the present, that the amount of ter evaporated from the surface of the irrigated area, together h that transpired by the leaves of cultivated plants, would aggre- e a depth of 12 inches during the three months from June 15 to ptember 15, the loss due to evaporation over an irrigated area of 625 acres would equal 38,625 acre-feet. Again, if we assume that water evaporated from the surface of the uncultivated portions the valley was 4 inches during the same time, this loss over an a of 450 square miles, less 38,625 acres, or 249,375 acres, would ual 83,125 acre-feet. Comparing the losses due to evaporation with gain from rainfall, the former is the greater by 35,830 acre-feet, ich would maintain a stream of 200 second-feet for nearly three nths.

f we assume that the rainfall just balances the evaporation, then gain due to seepage would be so given in the above table. In this e the amount evaporated from the surface of the uncultivated por- n of the valley in three months would be less than 2¼ inches, an ount apparently too small.

Irrigating duty of water in Cache Valley in 1896.

Month.	Duty of water in acres per sec. ft.
1896.	
June	52
July	67
August	113
September	166
Average	99.5

The figures given above include all the waste arising from absorption, seepage, and evaporation in the conveyance of the water as well as all waste caused by imperfect methods of irrigating.

FIG. 11.—Bear River at Collinston Utah.

SEEPAGE WATERS IN OGDEN VALLEY.

This valley comprises the highest irrigated land in Weber County. It is separated from Great Salt Lake Valley by a narrow spur of the Wasatch Mountains and is watered by the South, Middle, and North forks of Ogden River and several small creeks. The three main tributaries meet near the lower part of the valley and form Ogden River,

h traverses the mountain range through a canyon over 5 miles , having an average fall in that distance of 80 feet to the mile. torrential character of the river in this portion is illustrated in 12. All of the water flowing from the upper valley must pass ugh this narrow gorge.

ie irrigators of Ogden Valley supply annually 5,600 acres with r diverted from Ogden River and its tributaries, as shown by the l map, Pl. III. This diversion is, however, illegal during times

FIG. 12 Narrows of Ogden River.

scarcity, since all the summer flow belongs to prior appropriators ose canals are situated in the lower portions of the county, the ative location being shown on the left half of Pl. III. Many dis- tes have arisen between the irrigators of the two sections, and to event costly litigation, the writer sought to determine, if possible, ether water could be diverted and applied to the land in the upper lley without lessening materially the supply to the legal owners low.

The results of measurements made in 1894 are given in the follo ing table:

Ogden Valley inflow and outflow in 1894.

Date.	Inflow, in second-feet.	Volume used in irrigation.	Outflow, in second-feet.	Seepage waters and private springs.
July 10	154.0	140.0	156.5	142.5
15	129.8	121.0	140.7	131.9
20	127.2	104.7	119.2	96.7
25	118.6	93.5	105.4	80.3
30	107.1	85.0	106.8	84.7
Aug. 5	96.0	77.5	99.7	81.2
10	88.5	74.0	106.8	92.3
15	81.2	71.4	100.5	90.7
20	76.5	66.0	106.8	96.3
25	75.0	56.5	110.4	91.9
30	73.1	44.0	113.0	83.9
Sept. 5	80.2	31.0	121.2	72.0
10	79.0	27.0	119.2	67.2

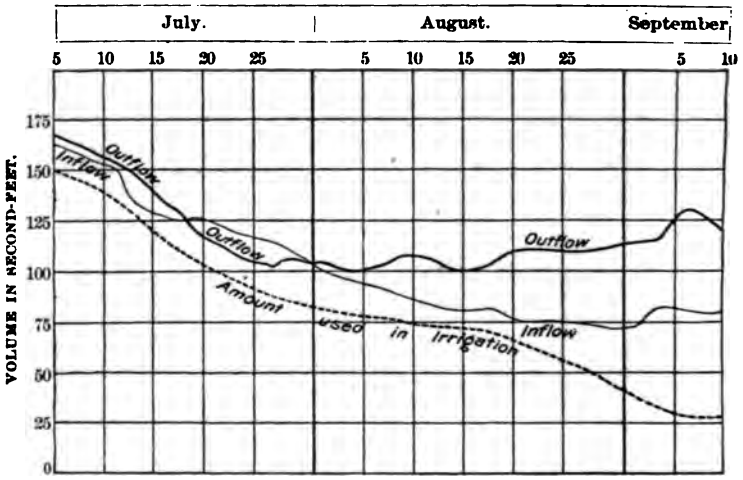
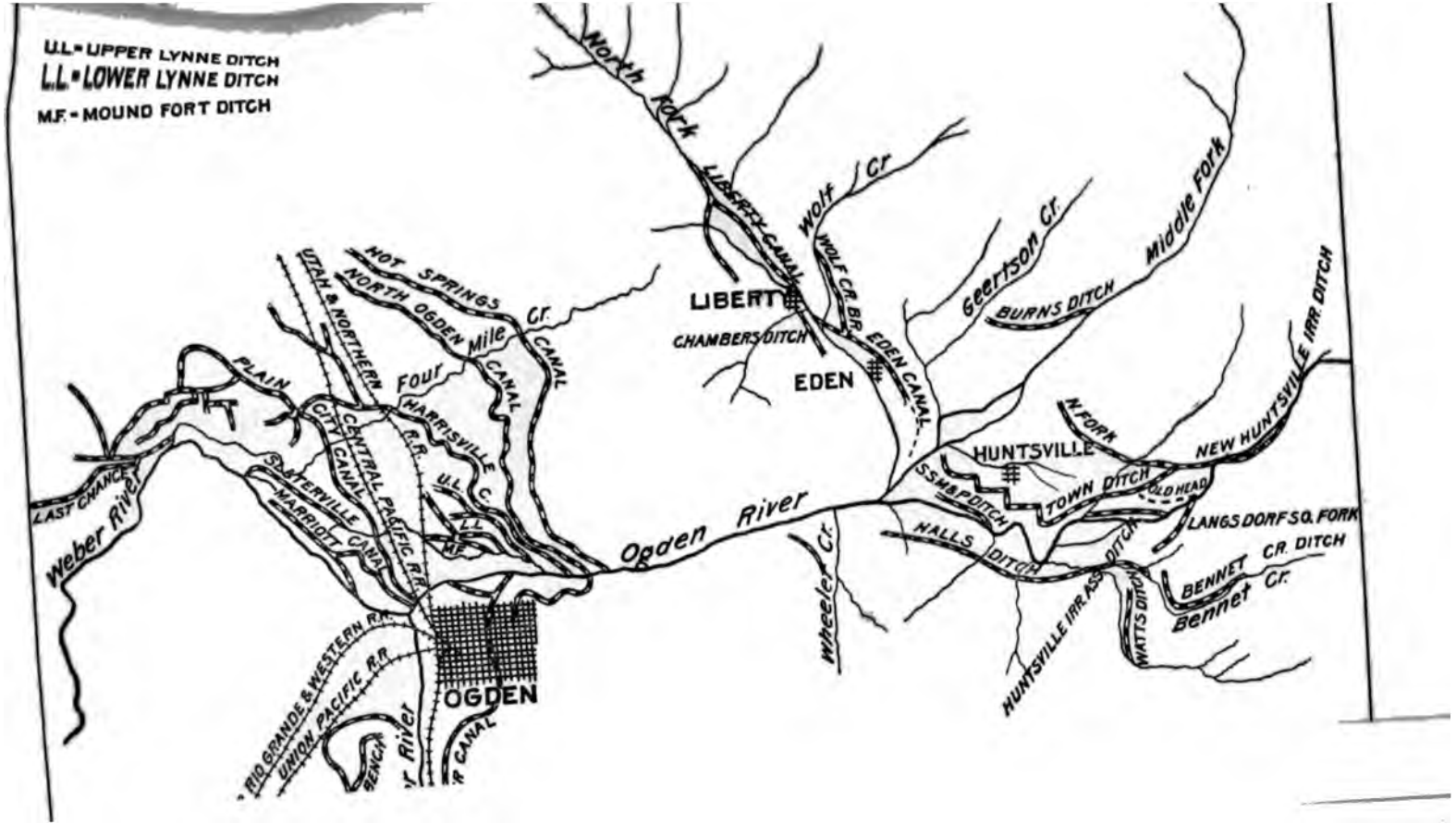


FIG. 13.—Diagram illustrating inflow and outflow of Ogden Valley.

A more detailed description of the measurements is to be found a preliminary report on seepage water and the underflow of rive published in 1895. The general facts are illustrated by the accom nying diagram, fig. 13, illustrating the inflow and outflow of Og

[1] Utah Agricultural Experiment Station Bulletin No. 38, by Samuel Fortier, hydraulic neer, February, 1895.


U.L.= UPPER LYNNE DITCH
L.L.= LOWER LYNNE DITCH
M.F.= MOUND FORT DITCH
North Fork
LIBERTY CANAL
Wolf Cr
WOLF CR. BR. EDEN CANAL
Geertson Cr.
Middle Fork
BURNS DITCH
LIBERTY
CHAMBERS DITCH
EDEN
HOT SPRINGS
NORTH OGDEN Mile Cr.
CANAL
Four
UTAH & NORTHERN
PLAIN
FT
CITY CANAL
CENTRAL PACIFIC R.R.
HARRISVILLE R.R.
U.L. C.
L.L.
M.F.
SOUTERVILLE CANAL
MARRIOTT
LAST CHANCE
Weber River
Ogden River
N. FORK
NEW HUNTSVILLE IRR. DITCH
HUNTSVILLE
SS M & P DITCH
TOWN DITCH
OLD HEAD
LANGSDORF SO. FORK
HALLS DITCH
BENNET CR. DITCH
Bennet Cr.
Wheeler Cr.
HUNTSVILLE IRR. ASS. DITCH
WATTS DITCH
OGDEN
RIO GRANDE & WESTERN R.R.
UNION PACIFIC R.R
BENCH
R CANAL

ey, and by the dotted line the amount used in irrigation. If no r returned by seepage or was added by percolation from the adja- mountain lands, the outflow would be represented by the vertical ance between the dotted line representing the amount used in irri- n and the light line representing the inflow; but, as shown by the y line, the actual outflow is far greater than this, being larger at s than the inflow upon the corresponding dates.[1]

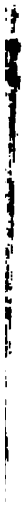
be more certain that the ratio existing between the inflow and ow of this valley was correctly determined in 1894, the writer Messrs. Rhead and Humphreys with a different current meter to a similar test during 1896. The results obtained by them, below, corroborate the records of 1894:

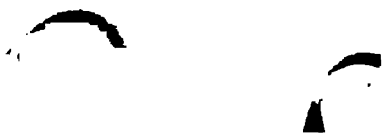
Results of measurements in Ogden Valley in 1896.

Date—1896.	Inflow in second-feet.	Volume used in irrigation.	Outflow in second-feet.	Seepage waters and private springs.
Aug. 20	91.6	106.5	101.1	116.0
25	86.0	99.2	99.5	112.7
30	78.7	89.4	97.4	108.1
Sept. 5	70.0	79.2	95.0	104.2
10	62.8	70.2	93.0	100.4
15	55.3	60.7	90.0	95.4
20	50.4	51.6	89.1	90.7

me of the Ogden Valley canals, such as the Eden Canal, obtain a ion of their discharge from seepage waters, and this accounts for fact that the aggregate volume used in irrigation exceeds the w.

[1] e public lands and their water supply, by F. H. Newell: Sixteenth Ann. Rept. U. S. Geol. y, Part II, 1895, p. 529.





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1895.

xteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895, octavo, 538 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the desert public lands; also a report on the water resources of portions of the Great Plains, by R. Hessig.

geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894, octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

eport of progress of the division of hydrography for the calendar year 1893–94, by F. H. Newell, 1895, octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

eventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896, octavo, 864 pp.

Contains papers by G. K. Gilbert on the underground water of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois, and by N. H. Darton on a reconnoissance of the artesian area in a portion of the Dakotas.

rtesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia and contains data relating to many of the deep wells.

eport of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 356 pp. Bulletin No. 150 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

ighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897, octavo, — pp. (In preparation.)

Contains a preliminary report of the stream measurements for the year 1896, by Arthur P. Davis, and four other papers relating to hydrography. The first of these is by Frank Leverett, and relates to the water resources of Illinois and Indiana, especially as obtained by wells; the next is by N. H. Darton on the artesian waters of South Dakota, being supplementary to his paper in the seventeenth Annual Report; there is a finely illustrated paper, by Jerome B. Sedgwick, on water storage, especially for irrigation, and the construction of dams; the last paper, by Robert T. Hill, describes the artesian conditions of a portion of Texas in the vicinity of San Antonio.

Water Supply and Irrigation Papers.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside or fourth page of this cover.

Survey bulletins can be obtained only by prepayment of cost as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier.
8. Windmills for irrigation, by E. C. Murphy.
9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker.
11. River heights for 1896, by Arthur P. Davis.
12. Water resources of southeastern Nebraska, by Nelson Horatio Darton.

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896-97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896; Stat. L., vol. 29, p. 453.)

The maximum number of copies available for the use of the Geological Survey is 1,000. This quantity falls far short of the demand, so that it is impossible to supply all requests. Attempts are made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules or donation of data. Requests specifying a certain paper and stating a reason for asking for it are attended to whenever practicable, but it is impossible to comply with general demands, such as to have all of the series sent indiscriminately.

Application for these papers should be made either to Members of Congress or to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 8

WINDMILLS FOR IRRIGATION.—MURPHY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888–89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 335 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889–90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 376 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890–91. Contains a report upon the location and survey of reservoir sites during the fiscal year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 80 plates and 100 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell, quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892, quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891–92, Part III, Irrigation, 1893, octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American engineering and engineering results of the Irrigation Survey," by Herbert M. Wilson; "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893, octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894, quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical condition and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892–93, in two parts, Part II, Accompanying papers, 1894, octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W. J. McGee; "Natural mineral waters of the United States," by A. C. Peale; "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 8

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1897

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

[NDMILLS FOR IRRIGATION

BY

EDWARD CHARLES MURPHY

WASHINGTON

GOVERNMENT PRINTING OFFICE

1897

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, April 13, 1897.

SIR: I have the honor to transmit herewith a manuscript entitled Windmills for Irrigation, by E. C. Murphy, professor of civil engineering in the University of Kansas, at Lawrence. This gives the results of experimental tests carried on during the summer of 1896 upon windmills located for the greater part in the vicinity of Garden, Kansas. These results are presented in condensed form for early publication in order that they may be available for use and discussion by persons interested in the matter. They should be considered as preliminary to a more popular presentation, which, however, can be given only when a considerable number of experimental measurements of various kinds have been completed and a careful study yielding general conclusions has been made.

In detailed work of this character it is impossible to avoid technical discussions and mathematical formulas, but as far as possible the results of the tests have been expressed in graphic diagrams. A careful study and comparison of these and of the accompanying descriptions shows the difference of behavior of the mills examined under the conditions in which they were found. It is, of course, impossible to draw conclusions applicable to all mills from the examination of a few, but the facts here shown are significant and worthy of careful consideration.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WINDMILLS FOR IRRIGATION.

By E. C. Murphy.

INTRODUCTION.

The windmill has long been employed to perform mechanical work. Just when and where the first windmill was used is not definitely known, but we know that a considerable number were utilized in France in the twelfth century. They were employed in Holland in the fifteenth century in pumping surface water over the dikes into the sea. It is not the purpose of this paper, however, to trace the history[1] or development of windmills, but to present the results of some recent measurements on the useful work windmills are doing, specially when employed to pump water. It is surprising to note how little definite information there is in regard to the efficiency of windmills, especially of the steel back-geared mills of the present day. Thousands, perhaps hundreds of thousands, are in use doing work of various kinds, and yet very few careful measurements have been made to determine their horsepower or the number of foot-pounds of work they are accomplishing under different velocities. It was to supply in a measure this lack that in 1895 the writer undertook to measure, with instruments then at his disposal, the pumping power of windmills. In 1896, with much better facilities, he continued this work, extending it to include power as well as pumping mills. The attempt was not made to measure the power of every make of mill; that was impossible. It was thought best to confine the work to different sizes of the standard mills, those that are used to a large extent and are giving satisfaction. In some cases two or three tests of the same size and make of mill were made for the purpose of showing the influence of the pump or well on the useful work done.

Perhaps nowhere in the United States is irrigation from wells by the use of windmills so extensively practiced as in the vicinity of Garden. Here are found hundreds of windmill pumping plants, irrigating from 1 to 15 acres, the pumps lifting from 3 to 14½ quarts per stroke to a height of from 10 to 45 feet. Here are found the large steel mills, with the latest improvements, running day and night whenever

[1] The Windmill as a Prime Motor, by Alfred R. Wolff, 1890, chapter 3, contains an account of the early history of windmills.

the wind velocity is sufficiently great. These reasons induced the writer to select this locality as the field of his investigations.

WELLS NEAR GARDEN, KANSAS.

A brief description of the water supply and the wells of this locality may assist in conveying an understanding of what follows. The water is found in sand and gravel at distances below the surface varying from 8 to 40 feet. This material is in layers of variable thickness and different degrees of coarseness, ranging from fine sand to large gravel. It is overlain by a layer of sandy clay, which in some places will stand vertical for years without any support. In other places there is very little clay in this layer. The wells are usually 3 to 4 feet square and cased with wood through the top [illegible] clay to the water-bearing sand; then a [illegible] or galvanized-iron casing from 12 inches [illegible] feet in diameter extends down from 8 to 20 feet into the sand to a layer of gravel. Where this latter casing is large, three or more galvanized iron pipes 6 to 12 inches in diameter are put down in the bottom of it, and these sometimes have wire gauze over their tops to keep down the sand. These galvanized-iron pipes have perforations about one-fourth inch in diameter for a distance of 2 feet or more from the bottom for letting in the water. In many cases instead of this small open well the supply pipe is on a well point whose diameter is the same as that of the supply pipe, and whose length varies with the diameter. These well points have not given satisfaction, and are being replaced by the open well.

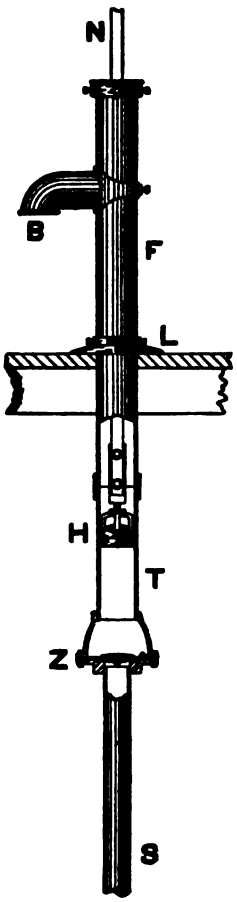


FIG. 1.—View of Gause pump. N, plunger; B, spout; F, discharge pipe; L, flange for platform; H, plunger; T, cylinder; Z, enlarged valve opening and check valve; S, suction pipe.

The difficulty with many of the wells is that they are not large enough; the water in them is lowered too rapidly, producing such a rapid inflow as to carry sand, which cuts the valves and cylinder lining.

PUMPS.

Nearly all the pumps in use in this vicinity with windmills are of the reciprocating-piston type. Fig. 6 shows what is called the Stone pump, manufactured by R. G. Stone, of Garden. They are made in three sizes—6-inch, 8-inch, and 10-inch, these dimensions being the approximate diameter of the discharge pipe. The

meter of the cylinder is less than this by twice the thickness of brass lining. The valves shown in fig. 7 are of the latest form;

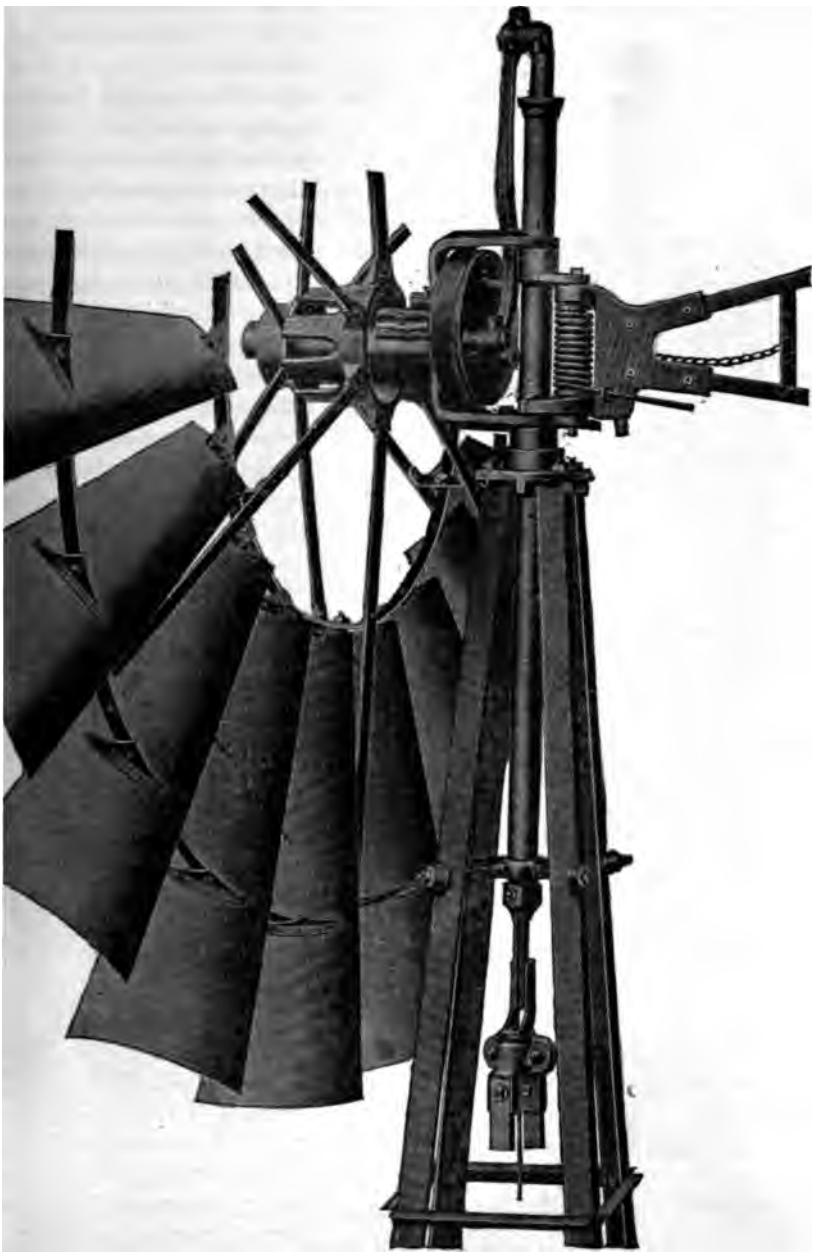


FIG. 2.—Working parts of Woodmanse Mogul.

plunger valve is of the single-flap or clack form, and the check the disk form, made so the water can pass up in the center as well

as around the sides. In an earlier form of this pump the plunger valve is of the double-flap or butterfly form, and the check of the lift form, but having no opening at the center. Probably nine-tenths of all the pumps in use near Garden are of the Stone variety. Fig. 1 shows the Gause pump, one of the first used there for irrigating purposes. It is more expensive than the Stone, and is not so much used now. Fig. 14 shows cylinder of 8-inch Frizell pump, a few of which are in use. Fig. 4 shows the Woodmanse pump, which is used with windmill No. 2. Fig. 24 shows a crude home-made pump called the "water-elevator." One of these is in use in Garden.

FIG. 8.—Sectional view of Woodmanse pump.

INSTRUMENTS AND METHODS.

The wind velocity was measured with a United States Weather Bureau cup anemometer. Each mile of wind was recorded electrically by one pen of a two-pen register. By means of a little device fastened to the pump an electric circuit is closed at each stroke of the pump and a record made by a recorder. Another electric circuit leading from the recorder to the other pen of the register is closed at each hundred strokes of the pump, and a record made on the register; hence the graphic record of the register shows the number of miles of wind in any given time, and also the number of hundred strokes of pump in the same time.

The anemometer was held on a pole at the height of the axis of the

wheel of the windmill. The pole was made so that its length could be increased at will from 25 to 50 feet. The anemometer on the pole is shown in Pls. I and VIII.

The discharge per stroke of the pump was found by catching the water for several strokes in a tub and measuring this with a quart measure. This was found to vary with the number of strokes per minute in a few cases on account of the valves leaking. The discharge given where it varied is for nearly a maximum speed of pump. The lift or distance from the surface of water in the well to the center of the water column as it leaves the discharge pipe was measured when the pump was working quite rapidly. For pump on well points it was estimated from the depth to water when the point was put down, making an allowance for the pumping down of the water.

In the following pages descriptions are given of each of the mills tested, these being illustrated by a few photographs of the mills and surroundings and by drawings of the common form of pumps employed. The descriptions are also accompanied by diagrams showing graphically the results obtained by the measurement of the velocity of the wind and by counting the number of strokes of the pump. These diagrams exhibit at a glance the facts which otherwise can be comprehended only by a careful study and analysis of the figures. As the wind increases from a gentle breeze the pumps run faster, the number of strokes per mile of wind increasing rapidly up to a certain point, but beyond this point the diagrams show that although the wind increases in speed, the pump begins to run slower. This apparent eccentricity is due to the simple fact that nearly all mills are so constructed that for safety they begin to turn out of the wind when it reaches a certain force, and thus decrease their revolutions, until in a heavy wind the movement becomes quite slow or may even cease altogether, the vanes being as a rule turned edgewise to the direction of the air currents.

In these diagrams (figs. 4, 8, 9, 10, 11, 13, 15, 16, 18, and 20) the relation between the movement of the wind in miles per hour and the number of strokes of the pump is shown by the curved line. The space from left to right on these diagrams is proportional to the velocity of the wind, while the distance from the lower line upward is proportional to the number of strokes of the pump. The data expressed by these diagrams were obtained directly from the record given by the anemometer register. The pen of this connected with the anemometer makes, we will assume, 3 short marks (3 miles) in 15 minutes, indicating a mile in 5 minutes, or at a rate of 12 miles an hour. At the same time the other pen, connected with the pump and registering each hundred strokes, makes, say, 2 short marks, showing that the pump has made 200 strokes for this 3 miles of wind movement, or 67 strokes in each mile. This fact is entered upon the diagram by placing a small circle at a distance from the right corresponding to 12

miles per hour and a distance from the bottom corresponding to 67 strokes. In this way each observation is indicated. When these points have been plotted, the smooth curve is sketched so as to occupy an intermediate position among these. In order to determine the number of strokes more accurately than was done by the automatic recorder, these were actually counted for a considerable number of the observations.

DESCRIPTION OF MILLS TESTED.

Mill No. 1.—The tests on this mill were preliminary or experimental toward the perfection of the instruments employed, and were not completed for discussion.

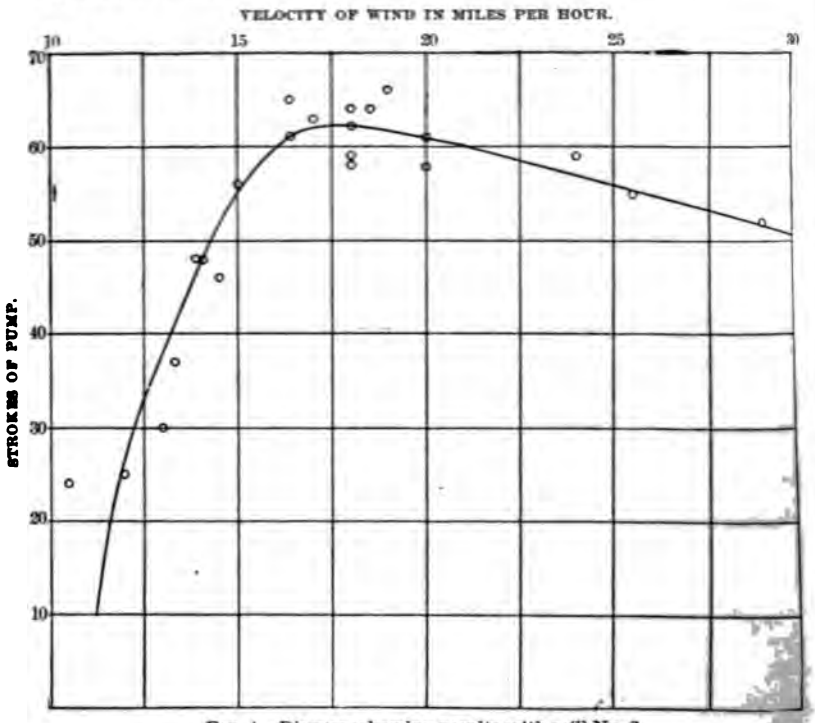


FIG. 4.—Diagram showing results with mill No. 2.

Mill No. 2.—This is a 12-foot Woodmanse Mogul, manufactured by Woodmanse-Hewitt Manufacturing Company, Freeport, Illinois. Pl. I shows the mill, tower, pump, and pond, and fig. 2 the working parts. The tower is steel, 50 feet high to the axis of the wheel. The wind exposure is not good from the north, the mill being 115 feet south of a large barn. The wheel has 30 curved fans, each 36 by 13 by 5½ inches, set at an angle of 30° with the plane of the wheel. It is back geared 3 to 1 and held in the wind by a spring. The pump is Woodmanse make, shown in fig. 3. The cylinder is 9½ inches in diameter; the supply pipe is 5⅝ inches in diameter; the length of stroke is 12

VIEW OF MILL NO. 2, WOODMANSE, AND ANEMOMETER.

he well is 3¾ by 3¾ feet to water, a distance of 14 feet. In of this is put down a 12-inch galvanized iron pipe 20 feet forming a small open well. The lift at the time of test et and the discharge per stroke 14½ quarts. The mean pressure was 26.98 inches, and the mean temperature 94°. mill, tower, pump, and well was about $210. The curve,

5.—Working parts of aermotor.

FIG. 6.—Stone pump.

ig. 4, is for a moderately loaded 12-foot mill (536.2 foot-stroke), and is seen to start with a wind velocity of about r hour. It ascends very rapidly, reaching a maximum at r hour, and giving 60 strokes per mile. The rest of the miles has a gentle slope; the number of strokes per minute, 5 at 12 miles to about 25 at 30 miles per hour.

Mill No. 3.—This is a 12-foot aermotor, manufactured by the Aermotor Company, Chicago, Illinois. Pl. II shows the mill with its tower, pump, and pond, and fig. 5 the working parts. This mill had been in use about a year and all the parts were in good working order. The tower is made of wood, having the axis of the wheel 30 feet above the ground. The exposure is very good. The wheel has 18 curved fans, each 44 by 18¾ by 7¾ inches, set at an angle of 31° to the plane of the wheel. It is back geared 3½ to 1, and is held in the wind by a spring. The pump is the Stone make (figs 6 and 7), in which the check valve is of the single-flap variety, and the plunger valve the double-flap variety. The cylinder is 9¼ inches in diameter; the

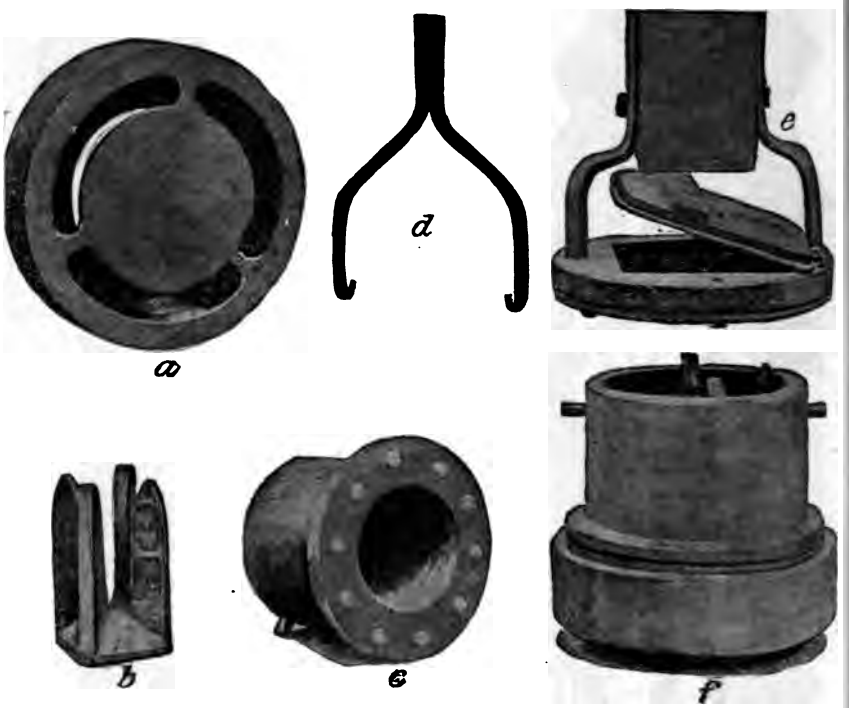


FIG. 7.—Valves of Stone pump. *a*, lower valve-seat; *b*, ring guide to lower valve; *c*, lower or check valve; *d*, hook for removing lower valve; *e*, plunger and valve; *f*=*a*, *b*, and *c* combined.

supply pipe is 4 inches in diameter, and the discharge pipe is 10 inches in outside diameter. The length of stroke is 12 inches and the discharge per stroke 14½ quarts. The well is 4 by 4 feet and is sunk a distance of 8 feet, being down nearly to water. From this to a depth of 18 feet it is 3 feet in diameter. In the bottom of this are three pipes 12 inches in diameter extending down 5 feet farther. The lift at the time of testing was 13¾ feet. The barometer pressure was 27.2 inches, and the temperature 85° F. The water is pumped into a pond 80 by 75 feet, and a depth of 22 inches can be drawn off. The *cost of the plant*, including mill, tower, pump, and pond, was $145.

ırve shown in fig. 8 is for a rather lightly loaded mill—415.3 nds per stroke. It starts at a velocity of 6 to 7 miles per eends less rapidly than in fig. 4, attains a maximum at about per hour, when the number of strokes per mile is 62, and then ; slowly, reaching 50 strokes at 30 miles. The number of ɔer minute increases from about 5 at 8 miles to 25 at 30 miles.

Vo. 4.—This, shown in the foreground of Pl. III, is an 8-foot ndmill, manufactured by the Stover Manufacturing Company, t, Illinois. This mill had been in use about one year and all s were in good condition. The tower is of wood; the axis of ɔl is 48 feet above the ground. The wheel has 15 fans, each

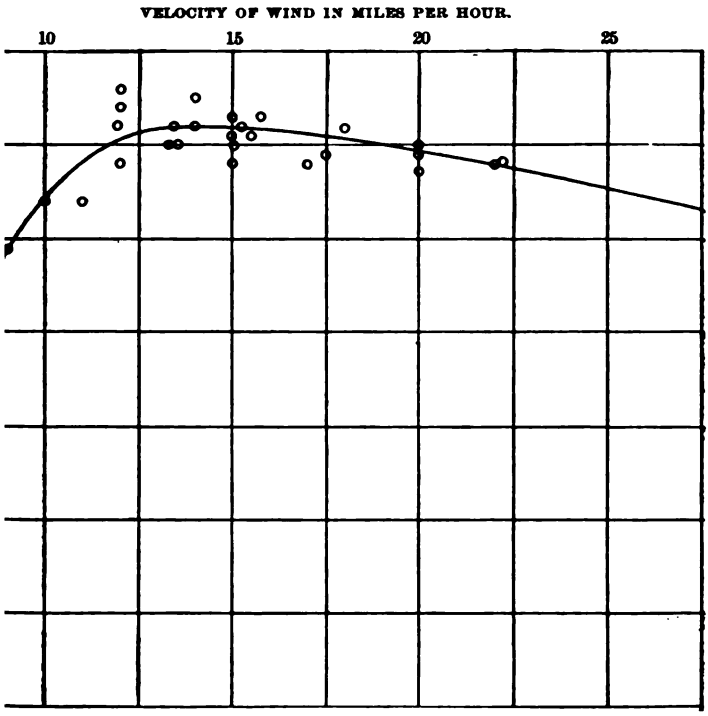


FIG. 8.—Diagram showing results with Mill No. 3.

by 30 inches, set at an angle of 29° with the plane of the It is back geared 2½ to 1 and is held in the wind by a spring. ıp is of the Stone make. The discharge pipe is 5⅝ inches in r and the supply pipe 3 inches in diameter. The length of ; 8 inches. The plunger and check valves are of the single- ety. The well is 2¾ by 2¾ feet down, nearly to water, a depth et. The 3-inch supply pipe extends down to a depth of 14 l on the end of it is a 3-inch well point 6 feet long. The lift y from 8½ to 20 feet. It was probably about 12 feet at the the test. The discharge per stroke was 2 quarts. The mean

barometer pressure was 27.19 inches, and the mean temperature
The water is pumped into a pond 115 by 31 feet and 3 feet deep.
cost of the plant, including mill, pump, well, and pond, was $80

The curve shown in Fig. 9, although for a quite lightly loaded
mill—50 foot-pounds per stroke—is seen to start in a 10 to 11
wind. The maximum is reached at 19 miles with a speed of 78 str
The right portion of the curve is quite steep and is characte
of this make of mill. Mill No. 18 is the same size and make a
one, and yet with a load of 89.2 foot-pounds it starts in a 7 to 8
wind, reaching a maximum at about 13 miles at a speed of 104 st
per mile. A second test, when the spring that holds the wind

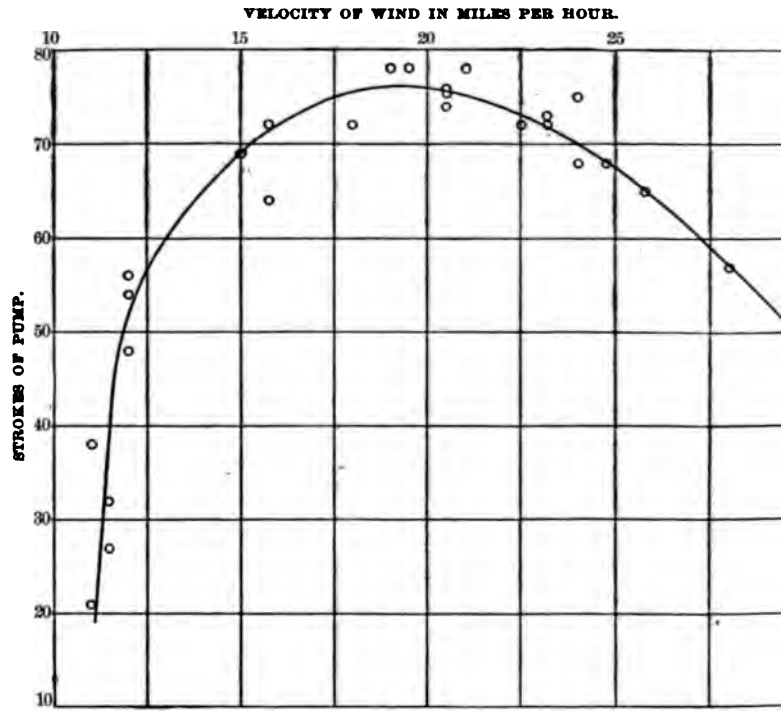


FIG. 9.—Diagram showing results with Mill No. 4.

in the wind was tightened up somewhat, gave the maximum
velocity of about 15 miles with a pump speed of about 114 str
The difference in performance appeared to be due to differen
pumps and wells.

Mill No. 5.—This mill, shown in the background of Pl. III,
8-foot aermotor, manufactured by the Aermotor Company, Chi
Illinois. The tower is of wood and is 28½ feet high to the axis
wheel. The exposure is good, and all the parts were in good
ing order at the time of examination, the plant having been i
about one year. The wheel has 18 curved fans, each 30 by 12½
inches, making an angle of 29½° with the plane of the wheel.

eared 3½ to 1. The pump is Stone make. The discharge pipe hes in diameter; the supply pipe, 3 inches in diameter. The are both of the single-flap variety. The length of stroke is 8

The well is 4 by 4 feet to water, a depth of 10½ feet. A 12- ooden curb extends 12 feet farther into the sand and gravel. ischarge per stroke was 3½ quarts and the lift 13 feet. The is pumped into a pond 110 by 30 by 2½ feet. The cost of including pond, was $80.

8-foot mill, with a load of 95 foot-pounds, is shown by fig. 11 with an 8 to 9 mile wind, reaching a maximum at 13 to 15 miles 5 strokes per mile. At 30 miles per hour it is making 77

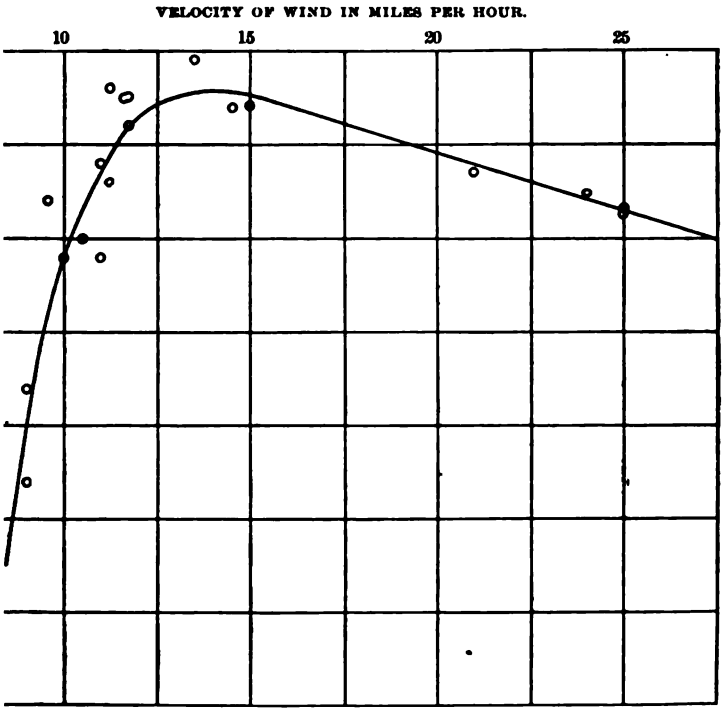


FIG. 10.—Diagram showing results with Mill No. 5.

s per mile and 39 per minute. This curve indicates a quite y loaded mill.

No. 6.—This mill, shown in the background of Pl. II, is an Gem, manufactured by the United States Wind Engine and Company, Kansas City, Missouri. The working parts of the e shown in Pl. IV. The exposure is good and all the parts are l working order, the mill having been in use only about a year. heel has 24 curved fans, each 30½ by 10 by 4½ inches, set at an of 35° with the plane of the wheel. It is back geared 3 to 1. heel is held in the wind by means of a weight. The pump is make. The discharge pipe is 6 inches in diameter, the supply

pipe 4 inches in diameter, and the length of stroke 8 inches. The well is open to water for a depth of 6½ feet. The supply pipe is on a well point, the end of which is 16 feet below the surface of the ground. The lift was $9\frac{7}{12}$ feet and the discharge $3\frac{8}{10}$ quarts per stroke. The tower is built of wood and is 24 feet high to the axis of the wheel. The mean barometer pressure was 27.02 inches and the mean temperature 85° F. The plunger valve is of the double-flap variety, and the check of the single-flap variety.

Mill No. 7.—This is a 12-foot aermotor similar to Mill No. 3. The tower is steel, having a height of 31 feet to the axis of the wheel. The exposure was good and all the parts were in good working order, the plant having been in use less than one year. The pump is the Stone make, and is like that with Mill No. 3, except that the check valve is of the solid-lift variety. The lift was 15½ feet, and the discharge $14\frac{3}{10}$ quarts per stroke. The water is pumped into a pond 135 by 50 by 2½ feet.

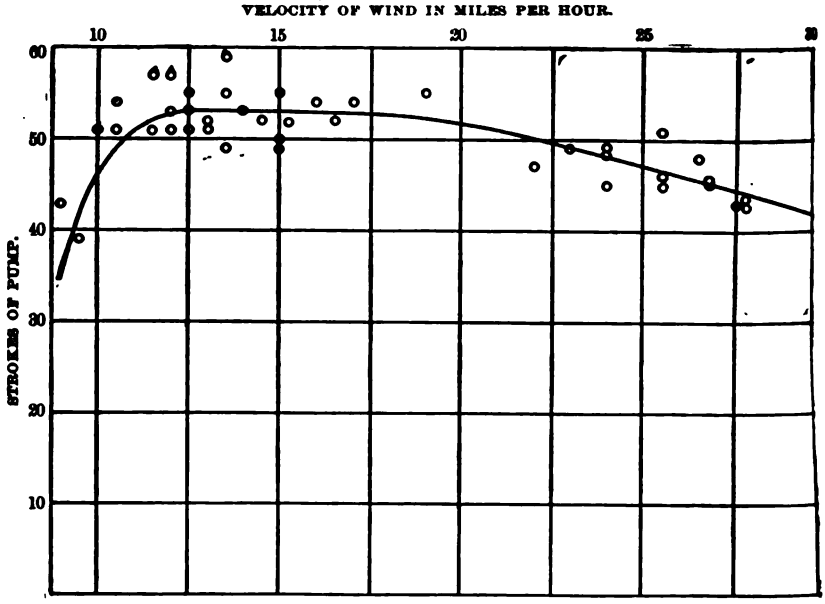
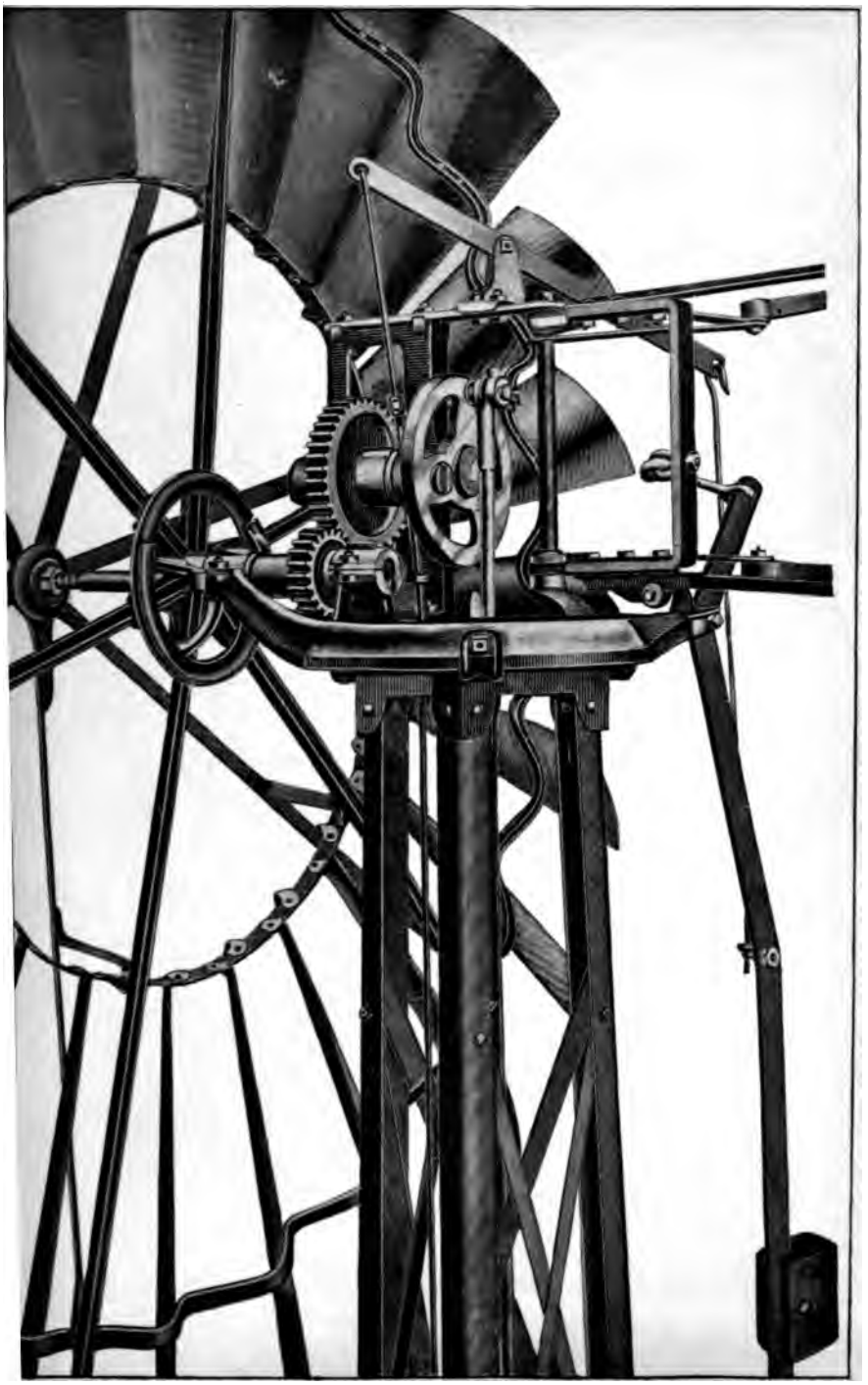


FIG. 11.—Diagram showing results with Mill No. 9, aermotor.

Mill No. 8.—This is a 10-foot Star wooden mill, manufactured by Bradley, Wheeler & Co., Kansas City, Missouri. The tower is made of wood and the axis of the wheel is 35½ feet above the ground. The water is pumped into an elevated tank 20 feet above the surface of the ground, and is used for irrigation. The wheel has 60 plain fans, each 37 by 5 by $2\frac{3}{4}$ inches, set at an angle of 33° to the plane of wheel. It is held in the wind by means of a weight. It is not back geared, a stroke of the pump being made to each revolution of the wheel. The supply pipe is 2 inches in diameter and terminates in a well point, the end of which is 18 feet below the surface of the ground. The cylinder



WORKING PARTS OF MILL NO. 6, GEM.

ıches in diameter, the discharge pipe 1¼ inches in diameter, the h of stroke 5 inches. The lift may vary between 28½ and 37 feet. s estimated to be about 30 feet at the time of measurement.

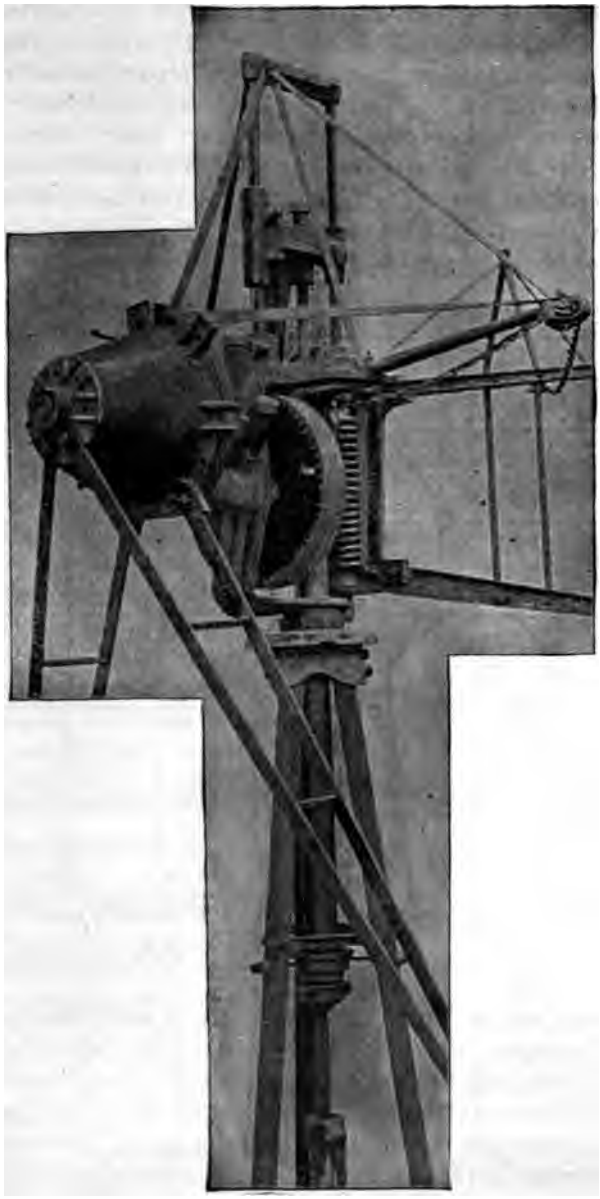


FIG. 12.—Working parts of Mill No. 10, Ideal.

lischarge per stroke was 0.24 quart. The cylinder leaked some ɜ time of test. After a new cylinder was put in the discharge

per stroke was increased to 0.40 quart. The mean barometer
was 27.04 inches; mean temperature, 78° F.

Mill No. 9.—This is a 16-foot aermotor. The tower is steel
axis of the wheel is 30 feet above the ground. The whee
curved fans, each 59 by 25¾ by 10½ inches, set at an angle of
the plane of the wheel. It is back geared 3½ to 1. The di
pipe is 12 inches in diameter, the supply pipe 6 inches in di
the cylinder 8 inches in diameter; the stroke, 16 inches. Th
4 by 6 feet to a depth of 23 feet, 2 by 2 feet down 8 feet farth
18 inches diameter down 14 feet farther. The water is 39½ fe
the surface of the ground. The lift is 44¼ feet and the disch
quarts per stroke. The check valve is of the single-flap vari
the plunger of the double-flap variety. The mean barometer p

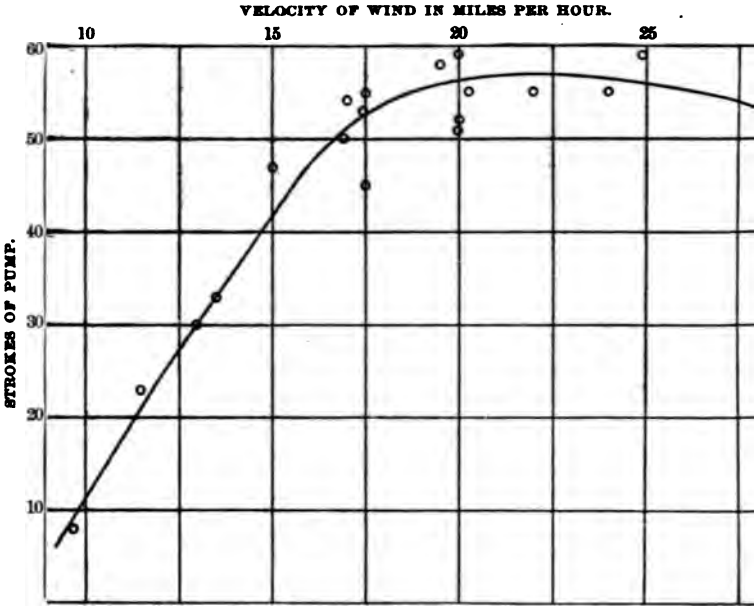


FIG. 13.—Diagram showing results with Mill No. 11, Ideal.

was 27.04 and the mean temperature 93°. This plant has bee
about three years.

The curve, shown in fig. 11, starts with a wind velocity o
miles and reaches a maximum at 13 miles, with a speed of 53
per mile. From this to a velocity of about 19 miles the curve i
horizontal. From this point it descends slowly to 32 miles,
is making 38 strokes per mile. The piston speed increases f
rate of 11 strokes at 12 miles to the rate of 21 strokes at 30 miles p

Mill No. 10.—This is an 8-foot Ideal. The tower is made
the axis of the wheel being 30 feet above the ground. The wh
15 curved fans, each 31 by 19 by 7 inches, set at an angle of 2
the plane of the wheel. It is back geared 2½ to 1. The sup

inches in diameter, the cylinder 2½ inches in diameter. The is of the common hand kind, with lift valve of the flap form and er of the lift variety. The leak some, as the dis- is greater when the pump king rapidly than when orking slowly. The supp- pe is on a well point 2 feet nd 1½ inches in diameter, lower end is 50 feet below rface of the ground. The s 33 feet and the discharge roke one-third of a quart pumping quite rapidly. ean barometer pressure .94 inches and the mean rature 97°.

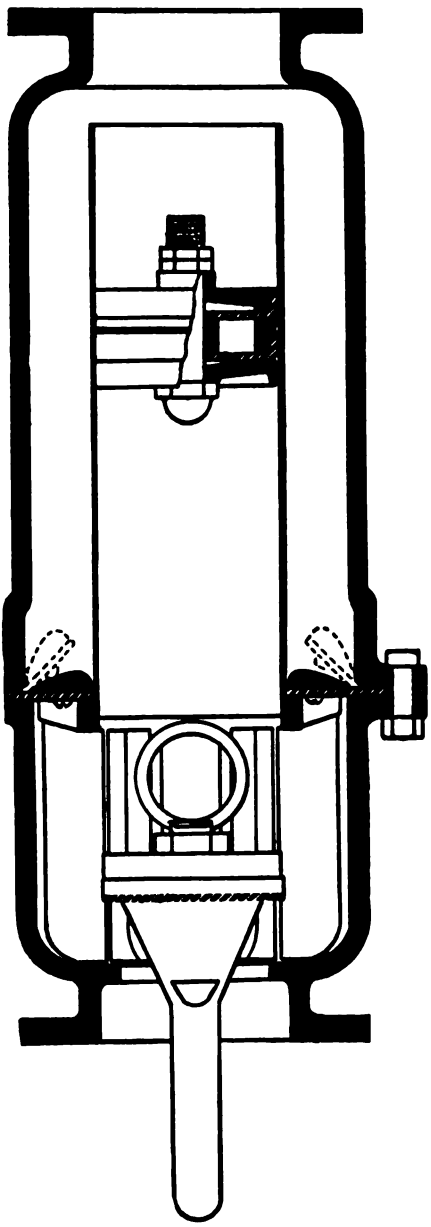


FIG. 14.—Working parts of Frizell cylinder.

No. 11.—This is a 12-foot the working parts of which own in fig. 12. The tower le of steel, the axis of the being 30 feet above the l. The exposure is good ll the parts are in good ng order. The wheel has ved fans, 31 by 19 by 7 , set at an angle of 29½° plane of the wheel. It is geared 2½ to 1, and the is held in the wind by a . The discharge pipe is es in diameter and the 12 inches. The supply onsists of two 3-inch pipes t long, each terminating inch well point 3 feet long. lves are both of the single- ariety. The water is 39½ elow the surface of the l. The lift, as nearly as e ascertained, was 45 feet time of measurement; the rge, 9 quarts per stroke. ter is pumped into a pond 40 by 6 feet. This plant has been in use about three years. ean barometer pressure was 26.91 inches, and the mean temper- 01° F.

This curve, shown in fig. 13, is for a heavily loaded (843.7 pounds per stroke) 12-foot mill. It starts with a velocity of abo miles per hour and reaches a maximum at about 23 miles, w piston speed of 57 strokes per mile. At 30 miles it is maki strokes per mile. The maximum point of this curve is much fa to the right than that of any other curve. The number of stroke minute increases from 5 at 12 miles to 25 at 30 miles.

Mill No. 12.—This is a 14-foot Ideal, shown in fig. 16. The t is made of steel, 30 feet high to the axis of the wheel. The w has 24 curved fans, each 48¾ by 17½ by 8 inches, set at an angle o with the plane of the wheel. It is back geared 2½ to 1. The p is Frizell make, shown in fig. 14. The discharge pipe is 10 inch diameter; the cylinder 9½ inches; the supply pipe is 6 inches in di

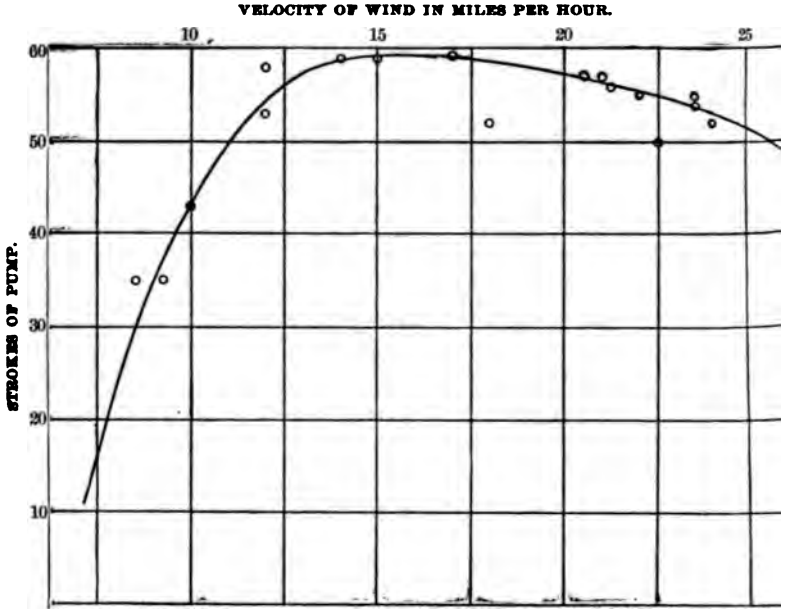
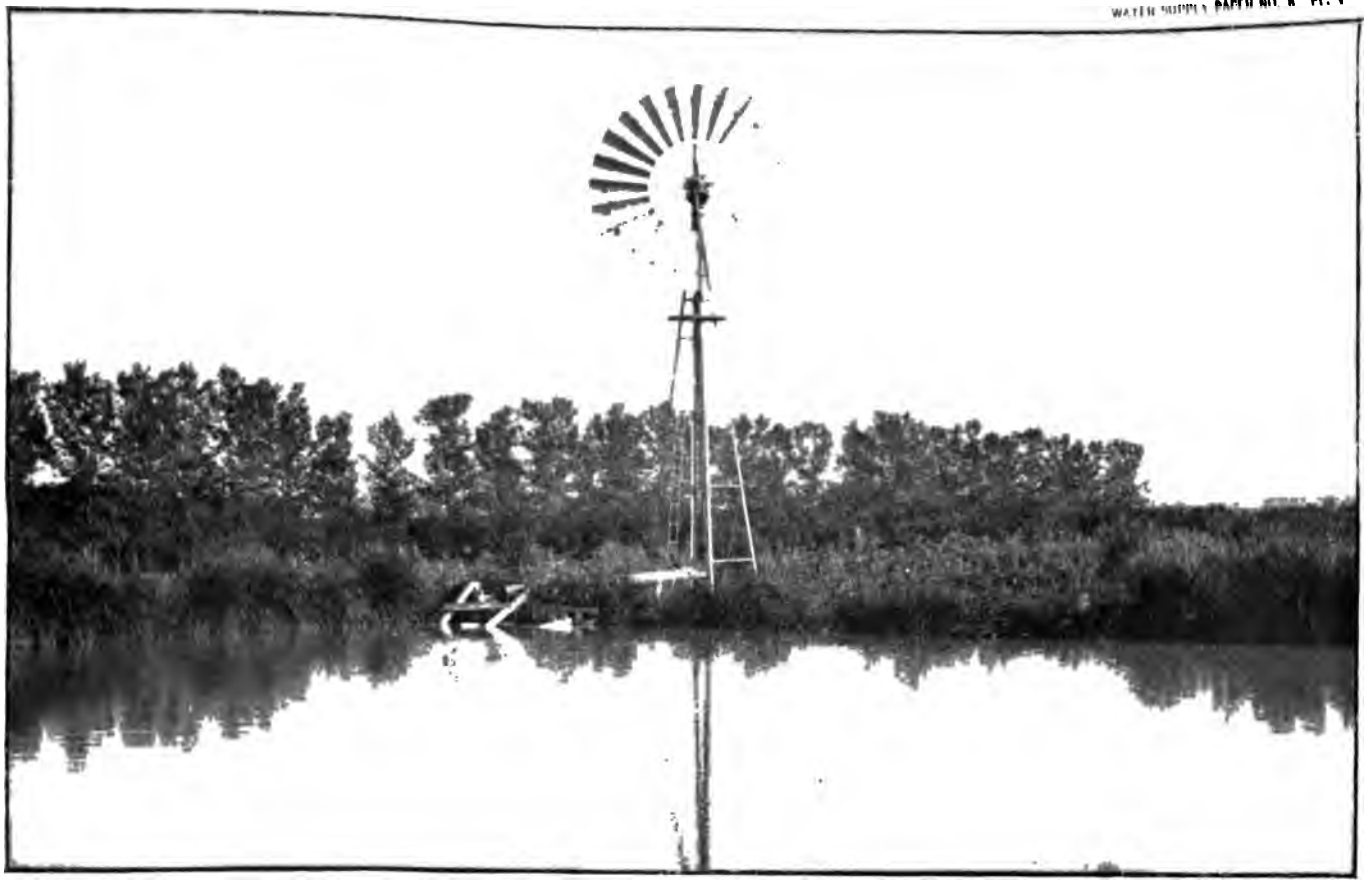


FIG. 15.—Diagram showing results with Mill No. 12.

eter, terminating in a well point 10 feet long and 6 inches in d ter, the lower end of which is 32 feet below the surface of the gr The lift, as nearly as could be estimated, was 11 feet; the disc 11.6 quarts per stroke. The mean barometer pressure was inches and the mean temperature 81° F. The water is pumpe a reservoir 100 by 100 feet and 3 feet deep. The pump has b use about one year.

The curve, shown in fig. 15, is for a very lightly loaded (263.5 pounds) 14-foot mill. This load is only 31 per cent of that of t foot mill, No. 11. The curve starts with a 7 to 8 mile wind and re a maximum at 15 miles with a piston speed of 58 strokes per n wind. At 30 the piston speed is 47 strokes.



Mill No. 13.—This is a 12-foot aermotor, shown in Pl. VI. The tower is made of wood, with the axis of the wheel 25 feet above the ground. The exposure is good and the plant in excellent condition, having been in use about one year. The wheel is the same as in mill No. 3. The pump is Stone make; the discharge pipe is 10 inches in diameter; the supply pipe is 5 inches in diameter on a well point 10 feet long, the lower end of which is 17 feet below the surface of the ground. The length of stroke is 12 inches. The plunger valve is of the double-flap type and the check valve of the single-flap variety. The discharge per stroke at the time of the test was 14.4 quarts and the lift about 11 feet. The mean barometer pressure was 27.09 inches and the mean temperature was 91° F. The important difference

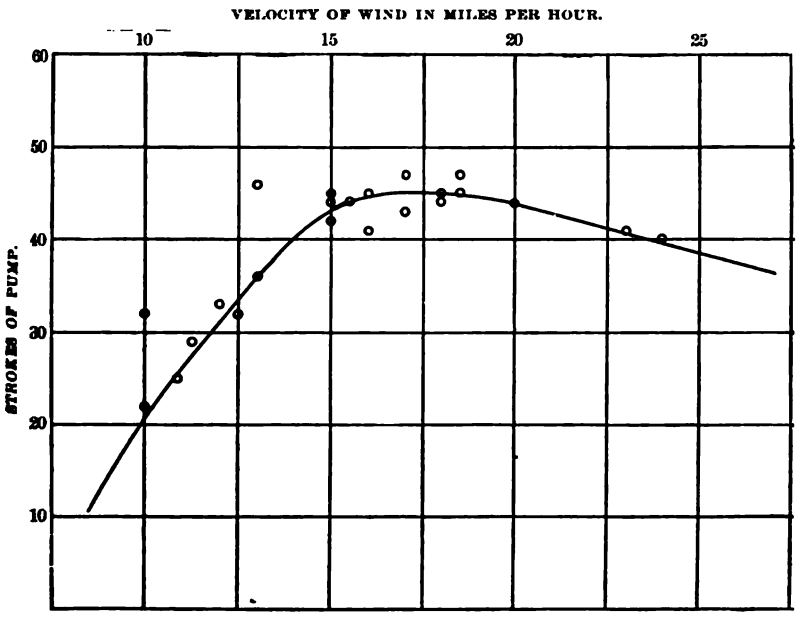


FIG. 16.—Diagram of results with Mill No. 19.

between this plant and No. 3 is that the latter has a 4-inch supply pipe and an open well, while the former has a 5-inch supply pipe on a well point.

Mill No. 14.—This is a 12-foot Gem, like the one shown in Pl. IV, on a 60-foot steel tower. The pump is Gause make; the cylinder is 8 inches in diameter; the length of stroke 9 inches. The supply pipe is a 12-inch open well. The discharge per stroke was 9¾ quarts and the lift 15½ feet. The wind velocity was not measured for this mill.

Mill No. 15.—This is a 10-foot Gem, similar to that shown in Pl. IV. The tower is made of wood, the axis of the wheel being 34 feet above the ground. The mill is in good working order, but the exposure is not good on account of trees. The wheel has 24 fans, each 36 by 11 by 4⅜ inches, set at an angle of 35° with the plane of the wheel. This

back geared 3 to 1. The pump is Stone make; the discharge pipe is 8 inches in diameter, the supply pipe 3 inches in diameter, the stroke 8 inches. The supply pipe is on a 3-inch well point 8 feet long, whose lower end is 21½ feet below the surface of the ground. The plunger valve is of the single-flap form and has a check lift. Depth of water is 10 feet. The discharge per stroke is 7 quarts; the lift, about 15 feet; the mean barometer pressure was 27.05 inches and the mean temperature was 84° F.

Mill No. 16.—This is a 10-foot Halliday, pumping water into the same pond as No. 15. It is similar to the mill shown in fig. 12. The tower is wood, and the axis of the wheel 28 feet above ground. The wheel has 78 fans, each 36¼ by 4 by 2¼ inches, set at an angle of 35½° to the plane of the wheel. It is not back geared. The pump is Gause

FIG. 17.—View of Mill No. 20, Jumbo.

make, with a discharge pipe 6 inches in diameter; the supply pipe is 4 inches in diameter. There is a 6-inch galvanized iron pipe forming an open well extending 15 feet into the water. The depth to water is 11 feet, the lift is 16 feet, and the discharge per stroke is 3 quarts. The mean barometer pressure was 27.02 inches, and the mean temperature 94° F.

Mill No. 17.—This is a 12-foot improved Gem on a 30-foot steel tower. The wheel has 32 curved fans, each 42 by 11½ by 4¾ inches, set at an angle of 37° with the plane of the wheel. It is back geared 2 to 1. The pump is Gause patent, with an 8-inch discharge pipe, 4-inch supply pipe, 12-inch stroke, and an open well formed of a 12-inch wooden casing. The depth to water is 17¼ feet, the lift 21¾ feet.

VIEW OF MILL NO. 13. AERMOTOR

e discharge per stroke 8¾ quarts. The mean barometer pressure
05 inches, and the mean temperature 93° F. This mill, although
new, does not work well. It is out of plumb. Only a few
ements of the number of strokes per mile of wind were made.
No. 18.—This is an 8-foot Ideal on a 36-foot wooden tower.
posure was good, and the parts were in good working order.
ieel is like that of Mill No. 4. The pump is Stone make, with a
lischarge pipe. There is no supply pipe, the cylinder being under
with 3½ inches opening to it from below. The valves are lift
for check, and single flap for plunger. The well is open,
by a 10-inch galvanized pipe in the bottom of a part 4½ feet
ieter and 8 feet deep. It is 11 feet to water. The lift is 14¾
id the discharge per stroke 2.92 quarts. The mean barometer
re was 27.01 inches, and the mean temperature 83° F. The
the plant, including pond, was $125.

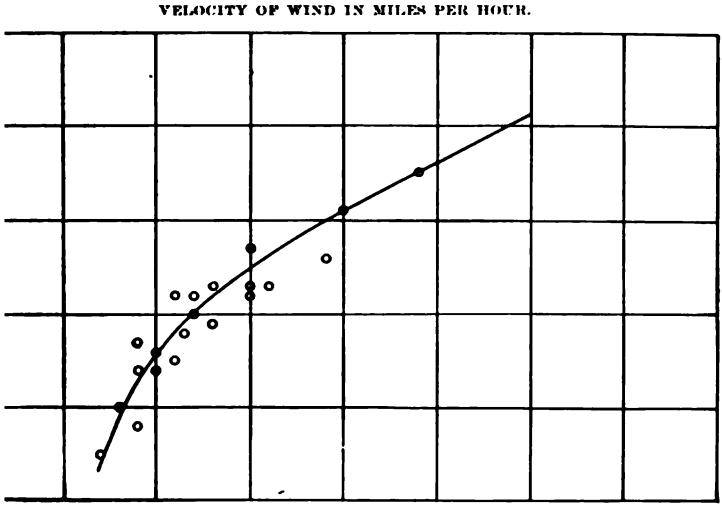


FIG. 18.—Diagram showing results with Mill No. 20.

No. 19.—This is a 12-foot Gem, shown in Pl. VII, on a 30-foot
i tower. The exposure is good, and the mill is in good work-
ler. The wheel is like that of Mill No. 17. The pump is Stone
with 10-inch discharge pipe and a 4-inch supply pipe. The
of stroke is 10 inches. The supply pipe is on a 4-inch well
feet long, the end of which is 23 feet below the surface of the
l. The check valve is of the lift type, and the plunger is of
gle-flap type. The lift was about 18 feet, and the discharge
oke 12 quarts. The mean barometer pressure was 27.13 inches,
e mean temperature was 70° F. The water is pumped into a
ir 120 feet by 60 feet.
curve, seen in fig. 16, shows that a 9-mile wind is necessary to
is mill, and that the greatest number of strokes per mile of

wind is 45, about 25 per cent less than most 12-foot steel back-ge mills. The piston speed is less than for other 12-foot mills, bein the rate of 6 at 12 miles and at the rate of 16 at 25 miles per hour

Mill No. 20.—This is a 15½-foot Jumbo, shown in fig. 17. Its

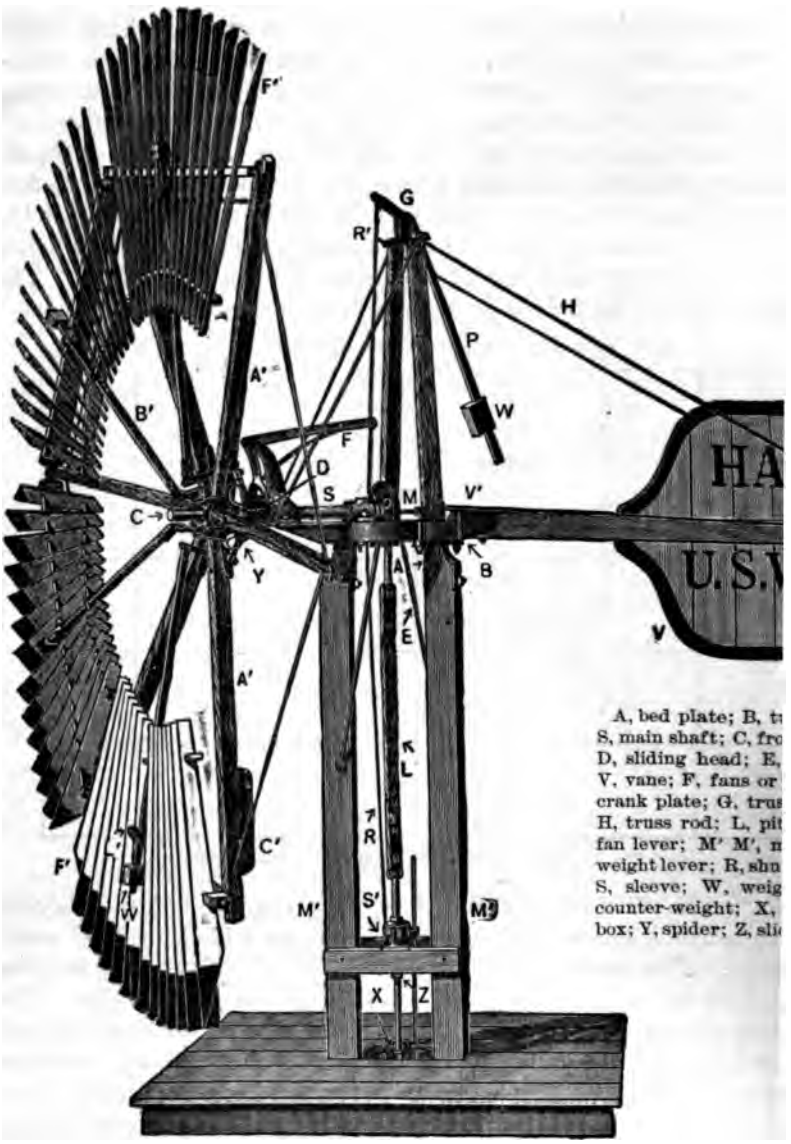


FIG. 19.—Working parts of Halliday mill.

is a steel shaft 8 feet above the ground. It has 6 fans, each 9½ feet; the outer radius is 7¾ feet and the inner 4¼ feet. This *operates* two pumps, one at each end of the axis, each having a (

VIEW OF MILL NO. 19, GEM

linder, a 3-inch discharge pipe, and a 3-inch supply pipe on a well int 5 feet long. The discharge of the two pumps was 10 quarts per roke; the lift was about 14 feet. The mean barometer pressure as 27.09 inches and the mean temperature was 85°. The anemomer was held 14½ feet above the surface of the ground, or at the elevation of the center of a fan when in its highest position. The wheel set in a large box extending up to a level with the axis of the heel to prevent the wind from striking the part of the wheel below s axis.

The curve, shown in fig. 18, is seen to be different from the others that it has no maximum. It starts with a velocity of 13 to 14 iles, and beyond 20 miles it appears to be nearly a straight line.

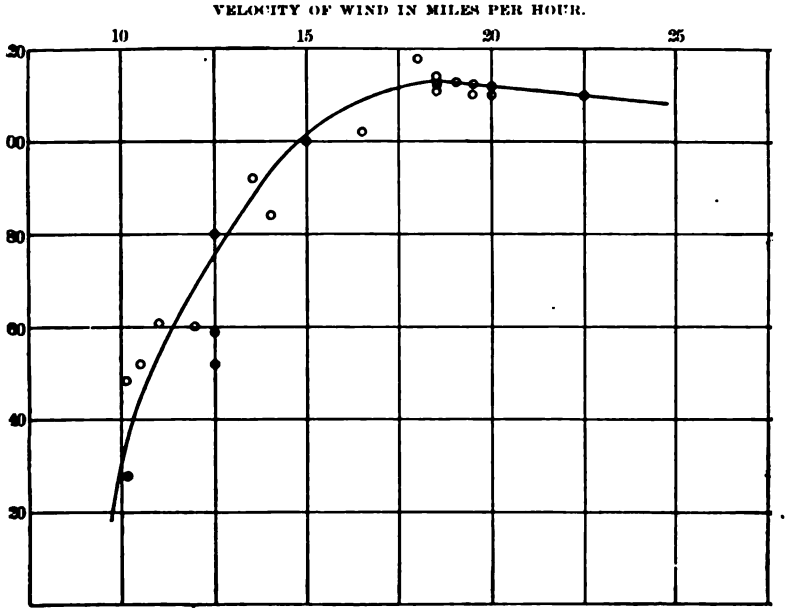


FIG. 20.—Diagram of results with Mill No. 21.

Mill No. 21.—This is a 12-foot Halliday, shown in Pl. VIII, on a 31-ot wooden tower. It was made by the United States Wind Engine d Pump Company, of Batavia, Illinois. The working parts are own in fig. 19. The wheel has 64 fans, each 42½ by 5 by 2⅜ inches, set an angle of 35° with the plane of the wheel. It is not back geared, d regulates itself on the centrifugal principle by the fans taking e direction of the wind. The pump is Stone make, with 7½-inch charge, 4-inch supply pipe, and 7-inch stroke. The check valve is form and the plunger double flap. The well is open, formed by wooden curb 12 inches in diameter sunk in the bottom of a dug ll 9 feet deep. The depth to water was 11½ feet and the lift 15 t. The discharge per stroke was 4½ quarts when pumping quite

rapidly (30 strokes per minute). The valves were not in ver repair, and the pump lost its priming after a time.

This curve, shown in fig. 20, for a lightly loaded (141. pounds), direct stroke 12-foot mill, is seen to start with a velo 9 to 10 miles, and to reach a maximum at 19 miles, with a pisto of 112 strokes per mile. At 30 miles the number of strokes is 98 per mile. The number of strokes per minute varies from 1 miles to 45 at 25 miles.

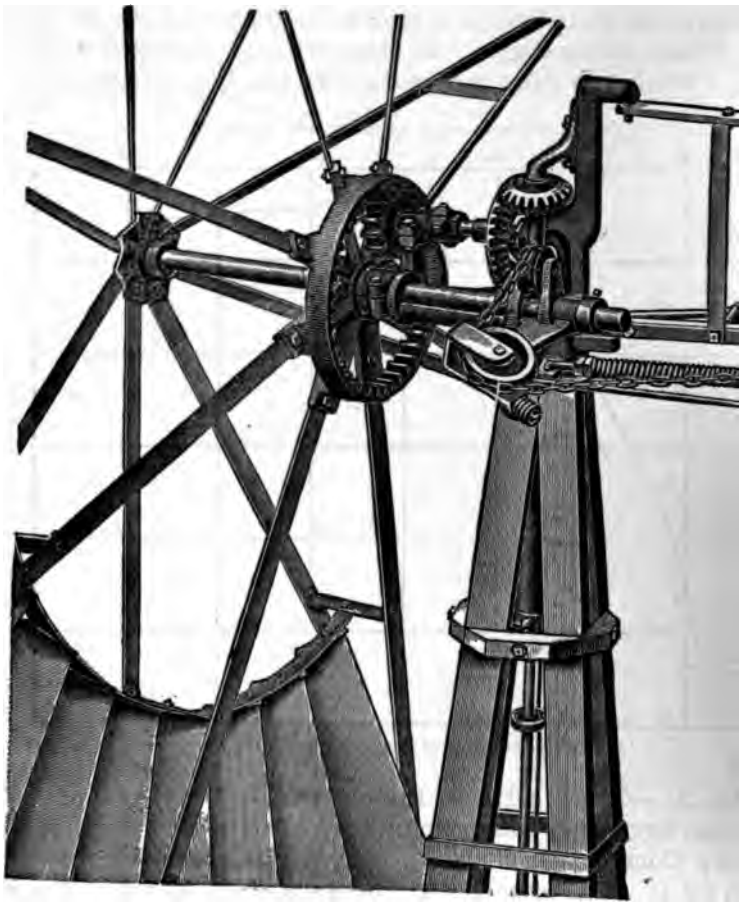


FIG. 21.—Working parts of Power Mill No. 26.

Mills Nos. 22 to 24.—The results obtained from these mills w sufficiently complete for discussion.

Mill No. 25.—This is an 8-foot steel mill, on a 32-foot steel made by Fairbanks, Morse & Co. The wheel has 18 curved fan 29 by 11⅜ by 5¼ inches, set at an angle of 29° with the plane wheel. It is back geared 2½ to 1. The pump is of the commo *variety, with* 2½-inch cylinder, 1½-inch supply and discharge

VIEW OF MILL NO. 21, HALLIDAY.

ach stroke. The well is open 6¼ feet to water. The discharge oke was 0.31 quart, and the lift 8½ feet. The water raised is r watering stock.

No. 26.—This is a 14-foot steel power mill, on a 40-foot steel nade by the Perkins Windmill Company, Mishawaka, Indiana.

FIG. 22.—Working parts of Power Mill No. 27.

orking parts are shown in fig. 21. The wheel has 32 curved ach 41 by 14¼ by 7¾ inches, set at an angle of 31° with the f the wheel. The shaft is geared forward 6 to 1; that is, the akes 6 revolutions to each revolution of the wind wheel. The was measured by the use of a Prony friction brake. The radius rake pulley was 5 inches, and the length of the brake arm 33¼

inches. The number of revolutions of the brake pulley per mile of wind was found from a speed counter. This mill was tested twice. Between the dates of testing, some repairs were made to the shafting, causing the cogwheels to bind less tightly. The figures given in Table I for this mill are those obtained from the second test, and are much larger than those from the first test. The load was 6 pounds on the arm 33¼ inches long. The mill has been in use about one year.

Mill No. 27.—This is a 12-foot power aermotor on a 30-foot steel tower. The wheel is the same as in mill No. 3. The horizontal shaft is geared forward 6 to 1. Fig. 22 shows the working parts of the mill and fig. 23 the foot gear. A 9½-inch brake pulley was clamped to the horizontal shaft at *a*, fig. 23. The power was measured by a Prony friction brake on this 9½-inch pulley, the arm of the brake being 35¼ inches in length. The number of revolutions per mile of wind was found from a speed counter. The mean barometer pressure on October 10, 1896, when quite a number of measurements of power were made, was 28.9 inches, and the mean temperature was 46° F. These have been taken as a standard, and measurements made on other days reduced to what they would have been had the pressure been at the standard.

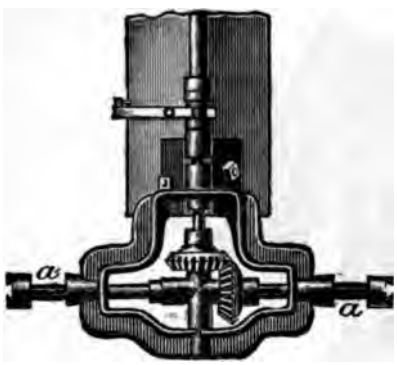


FIG. 23.—Foot gear of power mill No. 27.

DISCUSSION OF THE RESULTS.

The following table gives in condensed form the results obtained from the observations upon the windmills described in the preceding pages. This table shows, first, the arbitrary number given to each mill; next, the name of the mill and that of the owner of the particular one tested. Following this is the diameter of the wind wheel in feet. After this are four general divisions within which the observations have been classified according to the average velocity of the wind in miles per hour, beginning with a wind movement of 8 miles per hour and ending with one of 30 miles per hour. The number of strokes per mile of wind was obtained, as before stated, directly from the record given by the anemometer register. The second set of figures, that giving the number of strokes per minute, is obtained by simple division from the first set, the number of strokes per mile being divided by the number of minutes required for the wind to make a mile. The next set of figures gives the number of gallons per hour that each pump was lifting under the different wind velocities. This is found from the preceding set by multiplying the number of strokes per minute by sixty (number of minutes in an hour), and this *by the number of* gallons raised at each stroke.

The next set of figures, that giving the useful work in horsepower for the different velocities, is found from the preceding set by multiplying each of these by the factors which convert the number of gallons or the quantity of water raised through the given height into the corresponding horsepower. One horsepower is the rate of work when 33,000 pounds is raised to a height of 1 foot in one minute, or, in other words, is 33,000 foot-pounds. Thus to obtain the useful work in horsepower it is necessary to multiply the number of gallons by the weight in pounds of each gallon and by the height in feet to which this is raised, and to divide this by 33,000. This is expressed mathematically by the simple formula: Horsepower $= \frac{n\,q\,g\,h}{33{,}000}$, where n is the number of strokes per minute, q the number of gallons per stroke, g the weight in pounds per gallon, and h the lift in feet.

FIG. 24.—View of Defender mill and elevator.

The latter part of the table gives, after useful work in horsepower, the foot-pounds of useful work per stroke of the pump, this being obtained in the manner indicated above by multiplying the amount of water in pounds raised each stroke into the height in feet. Next to this is the total vane area of the mill in square feet, this being obtained by a careful measurement of the size of the vanes. Next to this is appended the total lift in feet, obtained as noted under the descriptions of the mills, and also the size of the pump (inside diameter of the cylinder) and the length of stroke, both of these being given in inches.

Results of measurements and computations of pumping mills.

Mill No.	Name.	Owner.	Size.	Number of strokes per mile of wind when velocity per hour in miles is—						Number of strokes per minute when velocity per hour in miles is—					
				8	12	16	20	25	30	8	12	16	20	25	30
			Ft.												
2	Woodmanse	I. L. Diesem	12	....	26	60	61	56	51	.....	5.2	16.0	20.3	23.3	25.3
3	Aermotor	T. D. Carless	12	40	60	62	60	56	50	5.3	12.0	16.4	19.8	23.1	25.0
4	Ideal	E. S. Austin	8	....	52	73	76	68	50	.....	10.2	19.3	25.3	28.1	25.0
5	Aermotor	Ella Horner	8	....	93	94	90	83	77	.....	18.6	25.1	29.8	34.6	38.5
6	Gem	W. J. James	8	....	62	67	66	61	58	.....	12.4	17.9	22.0	25.4	28.5
7	Aermotor	O. V. Folsom	12	....	57	59	57	53	47	.....	11.4	15.8	19.0	22.1	23.5
8	Star	J. C. Kitchen	10	210	150	.....	.....	.....	.....	28.0	30.0	.....	.....	.....	.....
9	Aermotor	F. M. Dunn	16	....	53	53	52	47	42	.....	10.6	14.1	17.2	19.6	21.0
10	Ideal	....do	8	106	125	125	.....	.....	.....	14.1	25.0	33.3	.....	.....	.....
11	....do	....do	12	....	24	48	57	56	50	.....	4.8	12.7	18.8	23.3	25.0
12	....do	D. M. Frost	14	23	55	59	58	52	....	3.1	10.9	15.7	19.2	21.5	.....
13	Aermotor	Wm. Coulters	12	....	55	64	63	59	55	.....	11.0	17.1	21.0	24.6	27.5
15	Gem	Jas. Allen	10	....	39	45	44	35	....	.....	7.8	11.9	14.7	14.6	.....
16	Halliday	....do	10	30	113	127	128	126	....	4.0	22.6	33.9	42.7	52.5	.....
17	Gem	D. R. Menke	12	....	30	48	52	.....	.....	.....	6.0	12.8	17.3	.....	.....
18	Ideal	Fred. Pile	8	60	101	{a 114	102	79	}	8.0	20.2	26.1	28.9	27.5	.....
						{ 98	84	66	}						
19	Gem	W. E. Trell	12	....	31	45	44	38	....	.....	6.2	11.9	14.7	16.0	.....
20	Jumbo	W. T. Cowhick	15½	....	....	20	32	42	....	.....	.....	5.3	10.7	17.5	.....
21	Halliday	J. E. Hunt	12	....	70	107	112	107	....	.....	14.0	28.5	37.3	44.6	.....
25	Fairbanks	Wm. Brown	8	92	146	140	114	80	....	12.3	29.2	37.3	38.0	33.3	.....

Mill No.	Number gallons pumped per hour when wind velocity per hour in miles is—						Useful work in horsepower when wind velocity per hour in miles is—						Foot-pounds useful work per stroke of pump.	Vane area, in square feet.	Lift, feet.	Size of pump. b
	8	12	16	20	25	30	8	12	16	20	25	30				
2	.....	1,131	3,480	4,415	5,069	5,503	.....	.085	.260	.322	.379	.411	536.2	69.4	17.75	9½x12
3	1,153	2,610	3,567	4,306	5,014	5,437	.067	.151	.207	.250	.291	.315	415.3	72.9	13.75	9½x12
4	.....	306	579	759	843	750	.....	.015	.029	.038	.043	.038	50.0	36.1	12.00	5½x8
5	.....	977	1,318	1,564	1,817	2,021	.....	.053	.072	.086	.099	.111	94.9	33.7	13.00	6 x8
6	.....	725	1,047	1,287	1,486	1,667	.....	.029	.042	.051	.059	.065	77.6	36.9	9.60	6½x8
7	.....	2,445	3,387	4,075	4,740	5,041	.....	.160	.221	.266	.309	.329	461.9	72.8	15.50	9½x12
8	101	108	.....	.....	.....	.....	.013	.014	.....	.....	.....	.....	15.0	59.8	30.00	3 x5
9	.....	1,749	2,326	2,838	3,234	3,465	.....	.325	.433	.448	.601	.644	1,013.3	133.6	44.25	8 x16
10	70	125	167	.....	.....	.....	.010	.017	.023	.032	.....	.....	22.8	42.0	33.00	2½x6
11	.....	648	1,714	2,538	3,150	3,375	.....	.123	.325	.481	.600	.639	843.7	75.3	45.00	7½x12
12	535	1,880	2,708	3,312	3,709	.....	.025	.087	.125	.153	.172	.....	263.5	103.6	11.00	9½x12
13	.....	2,376	3,694	4,536	5,314	5,940	.....	.110	.171	.210	.247	.275	330.0	72.8	11.00	10 x12
15	.....	819	1,250	1,543	1,533	.....	.....	.053	.082	.101	.099	.....	219.0	47.3	15.00	8 x8
16	180	1,017	1,526	1,922	2,362	.....	.012	.067	.103	.130	.159	.....	100.0	61.3	16.00	6 x8
17	.....	765	1,632	2,206	.....	.....	.....	.070	c.149	.202	.....	.....	385.0	75.8	21.75	8 x12
18	348	879	1,135	1,218	1,196	.....	.022	.054	(.082)	(.092)	(.088)	.....	89.2	42.0	14.75	5½x8
									.070	.076	.074	.....				
19	.....	1,116	2,142	2,646	2,880	.....	.....	.085	.162	.201	.219	.....	450.0	77.6	18.00	10 x10
20	.....	.....	795	1,005	2,025	.....	.....	.....	.047	.095	.154	.....	291.2	73.6	14.00	6 x12
21	.....	945	1,924	2,518	3,010	.....	.....	.060	.121	.159	.184	.....	141.5	69.7	15.00	7½x12
25	57	136	173	177	155	.....	.002	.005	.007	.008	.005	.....	5.5	30.2	8.50	2½x4

a Two pumps, each 6 by 12 inches.
b Inside diameter of cylinder by length of stroke.
c Test after increasing the tension of spring which holds wind wheel in the wind.

It is seen that mills of the same size differ very much in the useful work they do, and that some of the large mills are doing very little more work than some of the smaller ones. Nos. 4 and 18 are the same size and make; the wells, however, are very different; the latter is doing two or three times more work than the former. The 12-foot mill, No. 11, is doing nearly as much useful work as the 16-foot mill, No. 9, and three or four times more useful work than the 14-foot mill.

No. 12, while it is doing 300 per cent more work than No. 21. The 5½-foot Jumbo will probably do very little more work during the season than a good 8-foot mill.

RELATION BETWEEN WIND VELOCITY AND STROKES.

The preceding diagrams show graphically the relation between the wind velocity in miles per hour and the strokes of the pump. The curves, as will be noted, differ considerably; but with the exception of No. 23 for Mill No. 20, they agree in that they rise rapidly, reaching the highest point or greatest number of strokes at from 13 to 19 miles of wind velocity. From this point they descend slowly. They differ much in the position of the beginning of the curve, or the velocity required to start the mill. Some will run in an 8-mile wind; others require a 10 or 12 mile wind to start them. Some rise less rapidly than others; a notable case is Mill No. 11. Some descend much more rapidly than others after reaching the highest point. This is especially true of the 8-foot Ideals. Mill No. 12 (Pl. V) required a 14-mile wind to start it, and does not appear to have a maximum.

The shape of the curve, especially the position of its beginning point, is due to the load on the pump, or the number of foot-pounds per stroke. Increasing the load moves the curve to the right and raises it higher. This will be shown more fully in the discussion of power Mill No. 27. The height of the highest point and its position depend on the tension of the spring, or the weight which holds the mill in the wind. The greater the tension, the higher the summit and the farther it is to the right. Mill No. 20 has no method of reducing the wind area, and hence the curve has no summit, as shown in fig. 17. The less the tension in the spring, the steeper the descent from the highest point. The gearing—that is, the mechanism for causing the pump to make a stroke to each revolution of the wheel, or only a stroke every second or third revolution—modifies the curve. If working with a direct stroke, the curve is much higher and is farther to the right than if back geared, as shown by a comparison of mills 3 and 21, shown in figs. 8 and 20.

USEFUL WORK IN HORSEPOWER.

The relation between wind velocity and horsepower is shown graphically for five 12-foot mills on diagram No. 31 and for four 8-foot mills on diagram No. 32. Examining the five curves of fig. 25, we see that No. 11, the one which gives the greatest horsepower, has the heaviest load and requires the greatest wind velocity to start it. No. 2 has about five-eighths the load of No. 11, does less work, and requires about the same wind velocity to start the pump. No. 3 has a lighter load than No. 2 and will start in a wind of about 7 miles per hour. No. 19 has a little heavier load than No. 3 and does much less work

at all velocities. The latter requires a 9 to 10 mile wind to start it, while the former will start in a 7 to 8 mile wind. No. 21 is doing the least work of the five, and requires about an 11-mile wind to start it. It is a wooden mill working direct stroke, while the others are steel mills and back geared. It must be understood in this comparison that no correction or allowance is made for difference in temperature and barometric pressure, nor for the fact that in Nos. 11 and 19 the pumps are in well points, while in the others they are in open wells.

It is seen that in fig. 25 none of these curves reach a maximum

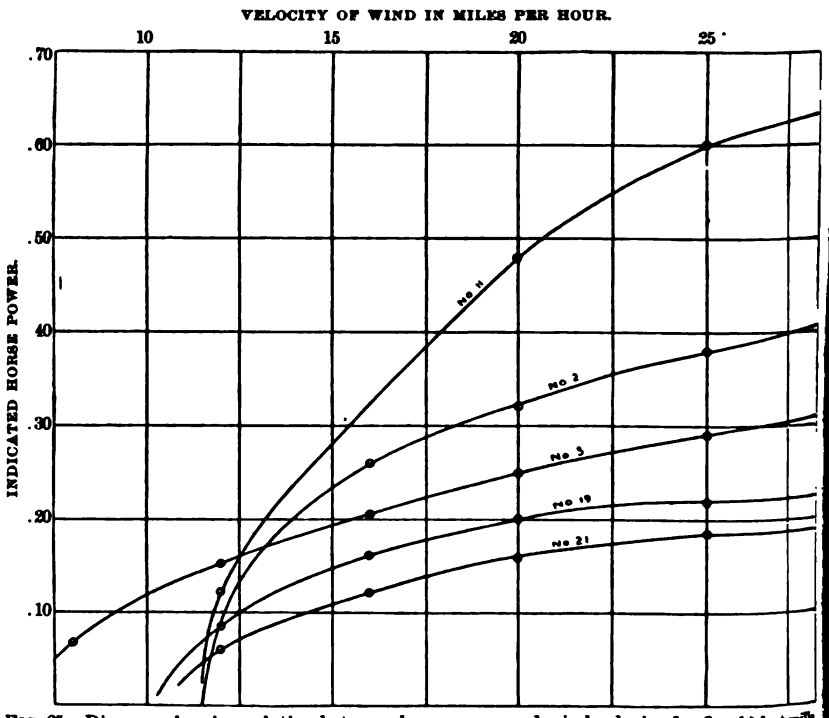
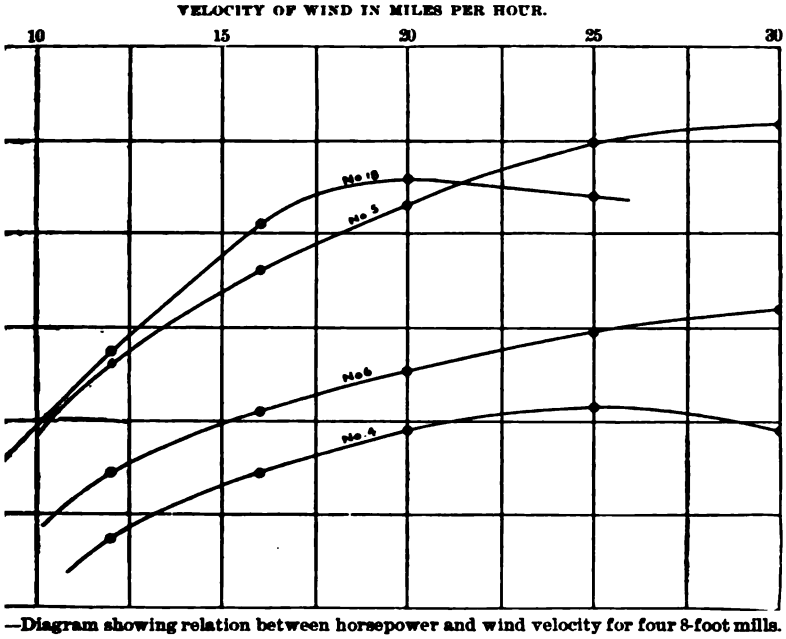


FIG. 25.—Diagram showing relation between horsepower and wind velocity for five 12-foot mills.

point below 30 miles per hour. They do, however, for some higher velocities, since the work per stroke of pump is nearly constant for each pump for all velocities, though not the same for one pump as for another. These curves also give the relation between wind velocity and number of strokes of pump per minute.

In fig. 26 the curve for No. 18 is seen to reach a maximum at 30 miles per hour, and No. 4 reaches a maximum at about 25 miles per hour. The others reach their maximum points for velocities at about 30 miles. These maximum points are points of greatest piston speed, and are produced by a reduction of wind area, the wind wheel turning out of the wind. This make of mill is seen to "govern" or turn out of the wind at a lower velocity than other makes. Comparing the curves *on diagram* No. 26, we see that the one doing the most work in high *velocities is* No. 5, the one which is the most heavily loaded. The

ipal differences between Nos. 4 and 18—the ones giving the most he least work for velocities less than 22 miles per hour—are in ad and well. No. 4 has five-ninths of the load of No. 18, and a well point. The two doing the least work are on well points. l No. 25 is used to pump water for stock. Comparing it with f, say, No. 5, we see that its load is about five-ninths, and that loing about one-tenth as much work as the latter. It will start a wind velocity of about 6 miles per hour, while the latter res a velocity of about 8½ miles.



—Diagram showing relation between horsepower and wind velocity for four 8-foot mills.

COMPARISON OF BACK-GEARED AND DIRECT-STROKE MILLS.

nparing the curves of fig. 25, which gives the relation between power and wind velocity for five makes of 12-foot mills, we see the one giving the least power is working direct stroke. It red the greatest velocity to start it, and is doing less work at all ities than any of the other four. In a 20-mile wind it is making okes per minute, and in a 25-mile wind 48 strokes per minute. is too rapid a rate; 30 strokes per minute is as rapid as a pump s size should work. Hence the horsepower of this mill would be han shown in the diagram if run at a proper rate. The only way it can be made to do more work without back gearing it is by asing the load per stroke, but this will increase the velocity sary to start it, and cause it to remain idle a greater part of me. Comparing the working of this mill and, say, No. 3, we see he work per stroke of No. 3 is 415 foot-pounds and that of No. 141 foot-pounds, or the former is doing about three times as much

work per stroke as the latter, and the latter is making about 1.8 times as many strokes per minute as the former in a wind velocity of 16 or more miles per hour. The former being back geared 3½ to 1, its wheel is revolving about 1.9 times faster than that of the latter. Now, examining the curves of fig. 27, we see that the speed of the wheel has much to do with the useful work done. When the speed is low, as it must be in a mill working direct stroke and not too rapidly for proper action of the valves of the pump, a slight increase in load reduces the speed a good deal. When the speed is nearly doubled, as in the case of Mill No. 3, the load may be increased considerably without reducing the speed much. Hence back gearing not only enables the mill to work with a given load in a much less wind velocity than one working direct stroke with the same load, but it enables the wheel to run at a velocity that gives more power.

PUMP LOAD DUE TO WELL POINT.

On examining well points that have been used for a time, it is seen that many of the little openings through which the water passes into the pump have become filled with fine grains of sand, thus reducing the area through which the water can enter the pump. If this area was of the proper amount when the point was new, it has become too small after having been used for a time, or after standing in the ground for a time without being used. If this area is too small to allow free flow into the pump, an added load is put on the pump.

To measure the mean pull of the pump, an instrument was devised by Mr. R. G. Stone, of Garden, consisting essentially of a spiral spring, whose compression was proportioned to the pull, and a pencil which moved up and down over a smooth surface. The spring was calibrated and the pull in the pump rods of four pumps measured with it. The four pumps selected were operated by the same size and make of mill, and the pumps were the same except as to size of supply pipe, valves, and kind of well. The discharge was practically the same, but the lifts differed slightly. These were Nos. 3, 7, 13, and 22. The following table gives the pull in each case after reducing to a common lift of 17 feet:

Added load due to pump.

No. mill.	Lift.	Kind of well.	Mean pull.
			Pounds.
3	13¼	Open	597
7	17	Open	734
13	12	4-inch well point	944
22	13¼	4-inch well point	819

The straining capacity of No. 7 is not as great as that of No. 3, and the resistance of the valves is greater in No. 7 than in No. 3.

USEFUL WORK DONE IN A GIVEN TIME.

The useful work which two mills of the same wind area, exposure, nd general character will do depends on the magnitude of the load n the mill and the wind velocity. If the mill is heavily loaded it ill do more work in velocities of 12 or more miles per hour, and less n lower velocities than one of a lighter load. The useful work done n a given time is the product of the work done per hour at the mean elocity, and the number of hours during that time. If the mean elocity at a given place is low, the mill load must be less for maxi- num work than that at a place where the mean velocity is higher. o illustrate this fact we use the results of tests of two 12-foot pump- ng mills (fig. 25): No. 11, heavily loaded, and giving the greatest orsepower of all the mills tested at high wind velocities; and No. 3, iving the greatest power at low velocities. The useful work per troke of pump is 844 foot-pounds for No. 11, and 415 foot-pounds or No. 3. The useless work of the former is greater than that of the tter, since the pump is on two well points in the former, while the ump of the latter is in an open well.

The relation between the horsepower and the wind velocity for ese mills is shown in the diagram (fig. 25). The curves are seen to oss each other at a wind velocity of 12½ miles per hour. For less elocities than this No. 3 is doing more work per hour than No. 11, nd for greater velocities No. 11 is doing more work than No. 3. If ie velocity at this place were, say, not more than 13 miles per hour, is very evident that mill No. 3 would do more work in any time than o. 11.

There is no record of wind movement at Garden, Kansas, for any onsiderable length of time. There is one, however, for Dodge, 50 iles east of Garden, kept by the United States Weather Bureau, hich may be used for this purpose. The following table gives the ean number of hours per month for the six months, April to Sep- mber, for the seven years 1889 to 1895, that the wind movement was -5, 6–10, 11–15, 16–20, 21–25, 26–30, 31 and upward miles per hour.

Mean wind movement at Dodge, Kansas, for the seven years 1889 to 1895.

Months.	0-5	6-10	11-15	16-20	21-25	26-30	31 and upward.
April	116	175	157	113	76	43	40
May	116	195	168	120	74	39	32
June	120	187	139	111	86	49	28
July	144	218	176	117	57	23	9
August ...	178	230	152	99	62	18	5
September	166	182	152	93	75	34	18
Mean .	140	198	157	109	72	34	22

It is seen from this table that the wind velocity is 5 miles or less per hour for 140 hours per month at this place. During this time neither of these mills will do any work, as neither will start in a 5-mile wind. The velocity is from 6 to 10 miles per hour for 198 hours per month. Mill No. 3 will start in about a 7-mile wind, and hence will run about four-fifths of this time, or 158 hours. No. 11 requires 11½ miles of wind to start it, and will do no work during this time. The velocity is 11 to 15 miles per hour for 157 hours during the month. No. 3 will work all of this time, and No. 11 about nine-tenths thereof, or 141 hours. Both mills are running for all higher velocities. Mill No. 3 will run (if in the wind) about 75 per cent of the time at this place, and No. 11 about 51 per cent of the time.

Comparative performance of two mills.

Velocities.	Mill No. 3.			Mill No. 11.		
	Hours.	Power.	Product.	Hours.	Power.	Product.
6–10	158	0.067	10.6	0	0.0	0.0
11–15	157	.168	26.4	141	.19	26.8
16–20	109	.230	25.1	109	.40	43.6
21–25	72	.277	19.9	72	.56	40.3
26–30	34	.308	10.5	34	.63	21.4
31 and upward	22	.320	7.0	22	.64	14.1
Sum			99.5			146.2

Columns 2 and 5 of the above table give the number of hours during the mean month that each mill was running with a wind velocity of from 6 to 10, etc., miles per hour. Columns 3 and 6 give the horsepower for the mean velocity; for example, 0.168 is the horsepower for No. 3 at 13 miles per hour, and 0.19 is the horsepower for No. 11 for the same velocity. Columns 4 and 7 give the product of the number of hours and horsepower that each mill is yielding during the month. It is seen that No. 11 is doing 31 per cent more useful work than No. 3. If this comparison is made for the month of August, it will be found that No. 11 will do 26 per cent more useful work during this month than No. 3.

POWER MILLS.

The working parts of Power Mill No. 27 are shown in fig. 22. Instead of the reciprocating motion of the pumping mill, there is here a central shaft which is caused to rotate by beveled cog wheels. The sizes of the cog wheels are so taken that this central shaft makes six revolutions to one of the wind wheel. The pumping mill being back geared 3⅓ to 1, and the power mill being geared forward 6 to 1, the vertical shaft makes twenty revolutions to one stroke of a pump

orked by a pumping mill whose wind wheel is running at the same ate as that of a power mill. At the lower end of this shaft is a foot ear, shown in fig. 23, on which is placed the pulley which runs the rinder or other machine.

The power that a windmill is capable of developing can be deter-nined better from a power than from a pumping mill, because the fficiency of the pump, which may be anything from 20 per cent to 85 er cent, is eliminated, and because the load on the mill can be varied t will, and thus the effect of load on the power can be determined or different wind velocities. To measure the power of this mill a pulley 9½ inches in diameter was fitted to the shaft at A, fig. 23, and a Prony friction brake, having an arm about 3 feet long, made to fit the pulley. A spring balance reading to quarters of a pound was made fast at one end, the other end being fastened to the arm of the brake. The speed of the shaft was found to be too great to be taken by a recorder, so a speed counter was used. By turning the nuts on the under side of the brake the spring balance could be made to read any desired number of pounds, and thus the load on the mill could be regulated. By holding the speed counter on the end of the shaft, throwing it in gear at the beginning of a mile of wind and throwing it out of gear at the end of the mile, the number of revolutions of pulley was found. The time of making the mile was also noted, from which wind velocity was found. If u equal the number of revolutions of pulley per mile of wind, L the load as shown by spring balance plus load of arm, and R the length of brake arm, we have the number of foot-pounds per mile of wind: Foot-pounds$=L\,u\,2\,\pi\,R$.

In fig. 27 are given four curves showing the relation between the number of foot-pounds per mile of wind and the wind velocity for four loads, namely, 6 pounds, 4 pounds, 2 pounds, and 0 pounds. These curves are constructed in the same way as those of figs. 4, 8, 9, 11, 13, 15, 16, 18, and 20, by drawing a smooth curve among a series of points whose ordinates are found from the above equation and whose abscissas are the observed velocity of wind, so as to have about as many points on one side as on the other. The left, or steep part, of each curve is the most difficult to determine, and has a less degree of accuracy than the rest of the curve: owing to the velocity being low, several minutes are necessary to make a mile, and the wind may vary considerably during this time. It may be nearly an average all the time and the mill scarcely move, or it may be twice as rapid the latter half of the time as the first half, and the number of revolutions for the same mean velocity will be quite different in the two cases.

Another reason why the steep part is less accurate is that a very little movement to the right or left of this portion will change the number of foot-pounds much more than in any other part of the curve. The curve A B is for no brake load. The brake was off the pulley: no useful work was being done, but the resistance of the moving parts

of the mill was being overcome. The pull necessary to overcome this resistance was found by standing on the platform of the mill and pulling the wind wheel around at uniform low speed with a spring balance. This was checked by winding a cord round the circumference of the wind wheel, and, standing on the ground, moving the mill when there

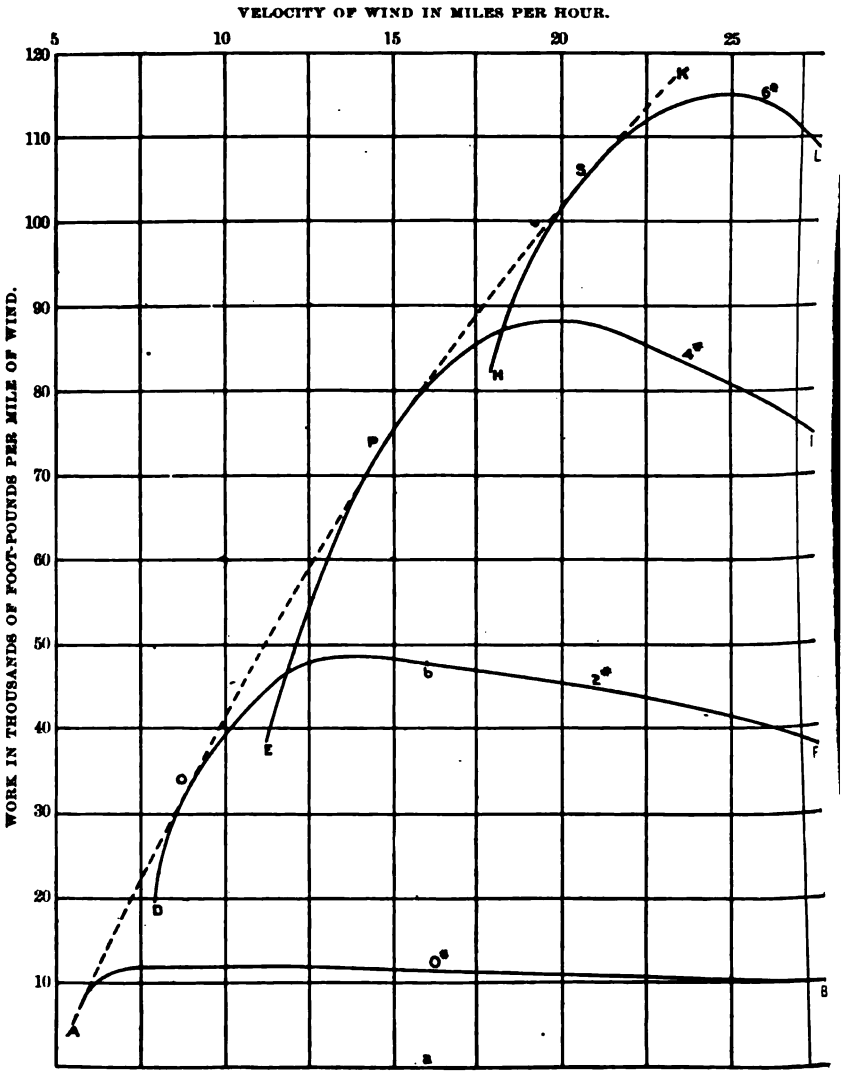


FIG. 27.—Diagram showing useful work for different loads of Mill No. 27.

was no wind by pulling on the spring balance attached to this cord. A pull of 1¼ pounds applied at the circumference (6 feet from center of wind wheel) was sufficient to overcome this resistance at a low velocity. Since the brake pulley is geared forward 6 to 1, the number of *foot-pounds* per revolution of brake pulley necessary to overcome this

resistance is 7.9. The number of foot-pounds per mile of wind for other velocities is then easily found from speed of brake pulley.

The greater part of this curve, A B, fig. 27, is seen to be a nearly horizontal straight line, the number of foot-pounds per mile of wind required to run the machinery being nearly constant. The other three curves of this plate are for useful work only; the useless work is not included in them. The highest point of these curves is seen to rise and move to the right as the load increases, and the part to the right of the highest point is seen to become more and more steep as the load increases. A broken line, A K, has been sketched tangent

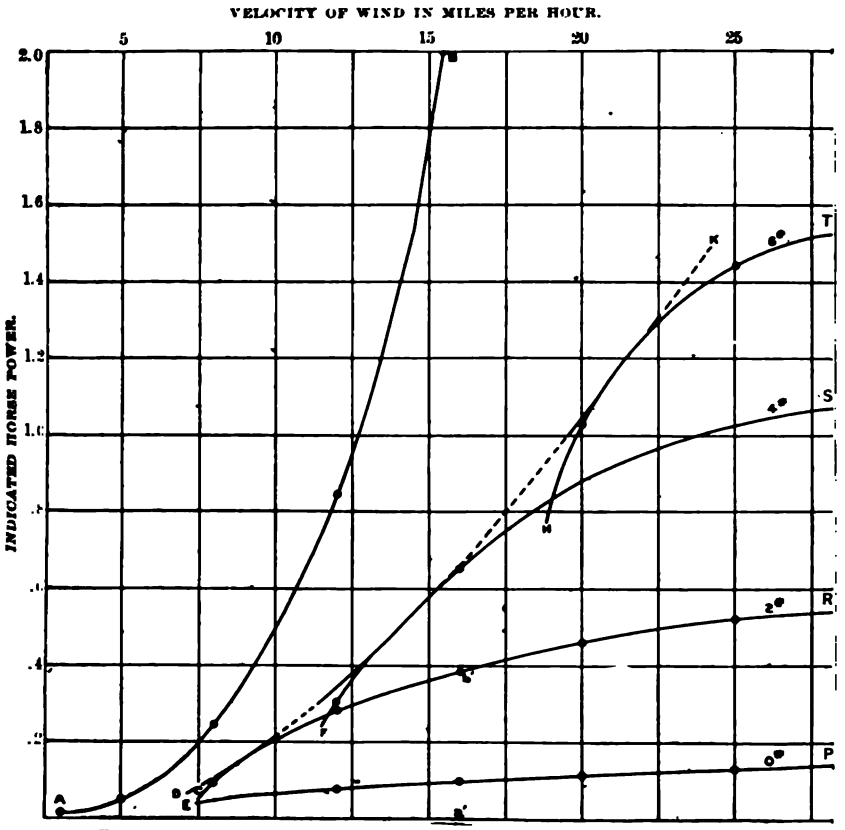


FIG. 28.—Diagram showing horsepower for different loads of Mill No. 27.

to these curves. It is the envelope of them and is concave to the horizontal coordinate axis. It would give the relation between foot-pounds per mile of wind and wind velocity if the load could be increased as the velocity increases.

Fig. 28 shows the relation between the horsepower and the wind velocity for the four loads—6 pounds, 4 pounds, 2 pounds, and 0 pounds. They are obtained from the curves of fig. 27 by reducing foot-pounds per mile of wind to horsepower; that is, for any velocity of, say, 16 miles per hour and load of, say, 2 pounds, divide

the ordinate a b, fig. 27, by $\frac{11}{16}$ (the number of minutes required to make the mile), and by 33,000, and we have the corresponding ordinate a′ b′ of fig. 28.

It is seen from these curves that for any brake load the power of the mill increases rapidly as the wind velocity increases, and reaches a maximum for some velocity greater than 30 miles per hour. As the load increases, the velocity required to start the mill increases rapidly and the curve becomes more steep. For a given wind velocity the power increases rapidly as the load increases. For a velocity of 30 miles the power is nearly proportional to the load for loads less than 6 pounds. It is seen that when the velocity is less than 12 miles a 4-pound load is too great, and when the velocity is less than 19 miles a 6-pound load is too great. The dotted curve D K, which is the envelope of these curves, gives the relation between power and wind velocity for a constantly increasing load. It is seen that there would be a great saving of power by the use of a device which would automatically increase the load as the velocity increases. The horsepower would then be given by the curve D K, instead of by one of the other curves.

Results of computations of power mills.

Mill No.	Name.	Owner.	Size.	Brake load.	Foot-pounds per mile of wind when hourly velocity in miles is—					
					8	12	16	20	25	30
			Ft.	*Lbs.*						
26	Perkins	Geo. Gilbert	14	6	.....	.....	.....	.....	.....	.....
27	Aermotor	E. C. Murphy	12	6	.....	.....	.....	101,500	115,000	104,200
27	....do....	....do....	12	4	.....	50,000	80,800	88,400	80,800	71,700
27	....do....	....do....	12	2	22,000	47,000	47,800	45,400	41,400	35,600
27	....do....	....do....	12	0	12,000	12,000	11,400	11,000	10,200	9,700

Mill No.	Brake load.	Foot-pounds per minute when hourly wind velocity in miles is—						Useful work in horse power when hourly wind velocity in miles is—						Vane area in square feet.
		8	12	16	20	25	30	8	12	16	20	25	30	
	Lbs.													
26	6	.....	.....	.....	.....	.....	.....	.....	.....	.313	.609	.937	.....	100.2
27	6	.....	.....	.....	33,883	47,917	52,100	.....	.....	.....	1.028	1.451	1.576	72.9
27	4	.....	10,000	21,530	29,367	33,667	35,850	.....	.303	.653	.890	1.020	1.086	72.9
27	2	2,933	9,400	12,747	15,133	17,250	17,800	.089	.285	.386	.458	.523	.540	72.9
27	0	1,600	2,400	3,040	3,667	4,250	4,850	.050	.073	.087	.111	.128	.151	72.9

TOTAL ENERGY OF THE WIND.

The curve A B shows the relation between wind velocity and the total horsepower possessed by the wind at the temperature of 46° F. and the barometric pressure of 28.9 inches. It is found from the relation $\text{Horsepower} = \frac{w}{2g} A \frac{V^3}{550}$ where w is the weight per cubic foot of air at this temperature and pressure, A the vane area equals 72.9

ɔt, V the velocity of wind in feet per second, and g the accel-
f gravity. w was found from the formula $w = \frac{T_0}{p_0} w_0 \frac{p^1}{T}$,
$T_0 = 273°$ C., $w_0 = .0807$ pounds per cubic foot, $p_0 = 14.7$
er square inch, $T = 281°$ C., $p = 28.9$ inches, and C = the
ıre expressed in centigrade degrees. Substituting these
orsepower = .00021 V^3.

EFFICIENCY OF MILL.

iding any ordinate of a load curve by the corresponding
ɔf this curve A B, we have the efficiency of the mill for this
velocity of wind.
y seen that the effi-
:reases as the veloc-
ses and as the load
The maximum
is given by the ratio
inate of the dotted
the corresponding
ɔf curve A B. This
for a load of 2
nd a velocity of 9
hour is 40 per cent,
wind area the sum
as of the fans. At
with a load of 4
is 36 per cent. If
at this velocity be
o 2 pounds the effi-
reduced to 24 per

shows the relation
oad and number of
ıs of the brake pul-
locities of 8, 12, 16,
130 miles per hour.

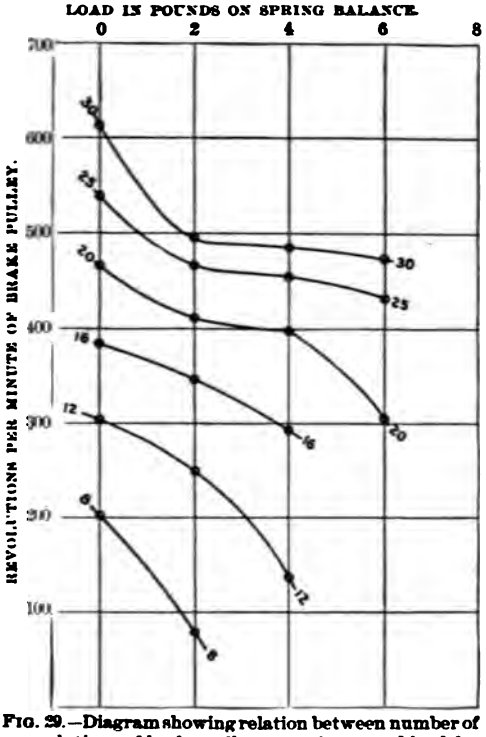


FIG. 29.—Diagram showing relation between number of revolutions of brake pulley per minute and load for different wind velocities for Mill No. 27.

how much the speed is reduced by a given change of
is seen that for a velocity of 8 miles per hour changing
from 0 to 2 pounds reduces the speed 60 per cent. When
ty is 12 miles, changing the load from 0 to 2 pounds reduces
about 17 per cent, and changing from 2 to 4 pounds reduces
50 per cent. When the velocity is 16 miles, changing the
ı 0 to 2 pounds changes the speed very little. When the
ɜ 20 miles, the speed remains about constant for 2 and 4

che's Mechanics of Engineering, p. 611, John Wiley & Sons, New York. Table
ı of computations of power mills.

pounds; at 25 and 30 miles the speed remains nearly constant for loads from 2 to 6 pounds.

MATHEMATICAL RELATION BETWEEN WIND VELOCITY AND POWER.

The relation between wind velocity and power of windmill is expressed graphically by the curves of fig. 28. The mathematical expression of this relation is given by Mr. A. R. Wolff on page 30 of his book, The Windmill as a Prime Motor, as Lv (or foot-pounds per second) $= \frac{s\,k\,c^2\,d}{g}\,v\left(\sin\alpha - \frac{v}{c}\cos\alpha\right)\cos\alpha$, where v=velocity of fan, s=surface of fan in feet, c=velocity of wind in feet per second, L=useful wind pressure on fan, d=density of wind, g=acceleration due to gravity, k is a coefficient, and α=the angle that the wind makes with surface of fan. It is seen that for a given wind velocity, density of air, and wind area, this expression for useful work is a function only of the velocity of the moving fan; it is not a function of the load on the mill. Fig. 29 shows that for a wind velocity of 30 miles per hour, and with a nearly constant velocity of wind area (v in the above formula), the load can be more than double, and thus the power more than doubled. It is evident, then, that however well this formula may give the power of the old Dutch mill or other modern mills not back geared, it gives results very much in error for a steel back-geared mill. Judging from the results of these tests, a formula giving the power of a steel back-geared mill should contain a factor which varies as the load on the mill varies.

GENERAL CONCLUSIONS.

1. The pumping power of windmills, or the useful work they do when raising water with reciprocating pumps of sizes from 4 to 10 inches diameter, is small—not greater that 0.65 of 1 horsepower for 12-foot mills, and much less than that claimed for them by some windmill makers.

2. The pumping power of windmills made for irrigating purposes is much greater than that of those which have been used for raising water for stock purposes.

3. The pumping power of the steel back-geared mills is greater than that of the wooden mills working with direct stroke.

4. The power of the Jumbo mill is much less—except for very high wind velocities—than that of the steel back-geared mills.

5. Well points produce a greater load on a windmill for a given lift and quantity of water than open wells.

6. Perhaps the most important result shown by these tests, and one that has not been clearly shown before, as far as the writer has seen,[1]

[1] Abstract of paper on "Windmills for raising water," by J. A. Griffiths: Proc. Inst. Civil Eng., Vol. 119, 1895, p. 15.

the influence of load on mill, or number of foot-pounds per stroke f pump on the power of a mill. The influence of this load factor on he power can be seen by comparing the power of two pumping mills f the same diameter whose loads differ considerably; but it is much etter shown by the tests of Power Mill No. 26. These tests show that or high velocities—25 or 30 miles—the power is very nearly proporional to the load on the mill. For 30 miles per hour, a brake load of pounds gave 0.54 horsepower; a 4-pound load, 1.09 horsepower; and a 6-pound load, 1.55 horsepower. The influence of this factor on the power is so great that if it is not properly taken into account, it obscures the influence of resistance of well points and the working of valves of pump or the efficiency of the pump.

7. Another fact brought out by these tests, and which follows as a result of the previous ones, is that there should be some automatic device for increasing the load on a mill as the wind velocity increases. When the velocity is low—say 6 miles per hour—the load should be small enough to enable the wind wheel to run at a rapid rate—the rate for maximum power—and then as the wind velocity increases the load should be increased, so as not to allow the wheel to run at a higher speed. This is a very promising field for the inventor.

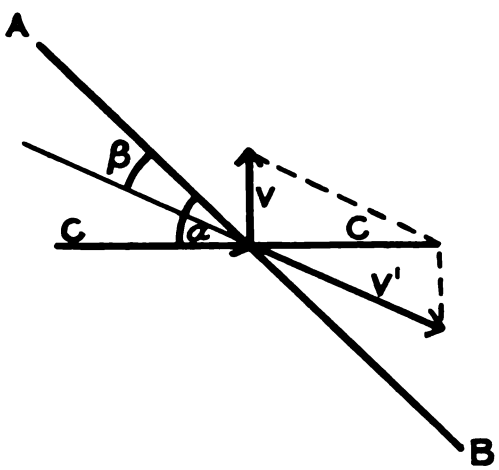


FIG. 30.—Diagram of forces acting on vane of mill.

8. If the load can not be automatically increased as the wind velocity increases, then the question arises, What is the proper or most economical load? This depends on the velocity of the wind each month at the given place. During the months of July and August there are a greater number of hours of low wind velocity than during any other two months of the year. The load should be light during these months for the greatest power. If the wind velocity is known, and the mill is one of the sizes and makes shown in the diagrams, the proper load can easily be computed. The mills in the vicinity of Garden, Kansas, would do more useful work if more heavily loaded.

It is seen that the useful work that a windmill will do when working under a constant load at all velocities is small, the horsepower varying as the first power of the velocity. By some device for auto-

matically increasing the load as the wind velocity increases, the power may be much increased at high velocities, and will then vary as the second power of the velocity. Even with this device for increasing power there is still a great difference between the power possessed by the wind and the power developed by the mill, and this difference increases as the velocity increases.

The reason why the windmill utilizes so small an amount of the energy of the wind may be seen from the following: Let A B, fig. 30, be a strip taken from the outer end of one fan of a windmill. It is curved, but for this purpose it may be considered a plane. This strip makes an angle α with the absolute direction of the wind. C represents the amount and direction of the wind; V represents the amount and direction of the velocity of the surface A B. Then the relative velocity of the wind—that is, its velocity with respect to the moving surface A B—is V′, the diagonal of the parallelogram constructed on V and C as sides, V′ makes an angle β with the sloping surface A B. If V=0—that is, if the wheel is held so that it can not revolve—the angle $\beta=\alpha$. As V increases β grows less and less, and finally becomes zero, in which case V′ is parallel to surface A B. In this case the surface receives no pressure from the wind—this portion of the fan is not utilizing any of the energy of the wind. If V be still further increased, β becomes negative, and the wind pressure is on the opposite side of A B. This portion of the fan is then doing work on the wind instead of the wind doing work on the fan. The effective wind area of a fan being the projection of the fan on a plane at right angles to the relative velocity of wind over it—that is, to V′—it is seen that as V increases the effective wind area decreases. The energy which the fan takes from the wind is proportional to the effective wind area. It is seen, then, that this reduction of effective wind area is the reason why the efficiency is low at high velocities. If this effective wind area could be kept constant by some device for changing the angle of the fans, the relation between wind velocity and horsepower might vary nearly as the third power of the wind velocity.

In this discussion we have not taken into account the reduction of wind area due to the wind wheel swinging out of the wind, or "regulating." The mill can be built strong enough so that it will not need to regulate for velocities less than 30 miles an hour.

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1895.

ixteenth Annual Report of the United States Geological Survey, 1894–95, Part II. Papers of an economic character, 1895, octavo, 588 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894, octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geological structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply for agricultural purposes.

eport of progress of the division of hydrography for the calendar year 1893–94, by F. H. Newell, 1895, octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

eventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896, octavo, 864 pp.

Contains papers by G. K. Gilbert on the underground water of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois; and by N. H. Darton on a reconnoissance of the artesian areas of a portion of the Dakotas.

rtesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 250 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

eport of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

ighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897, octavo, — pp. (In preparation.)

Contains a progress report of stream measurements for the year 1896, by Arthur P. Davis, and four other papers relating to hydrography. The first of these is by Frank Leverett, and relates to the water resources of Ohio and Indiana, especially as obtained by wells; the next is by N. H. Darton, on the artesian waters of South Dakota, being supplementary to his paper in the Seventeenth Annual. Following this is a fully illustrated paper, by James D. Schuyler, on water storage, mainly for irrigation and the construction of dams; the last paper, by Robert T. Hill, describes the artesian conditions of a portion of Texas in the vicinity of San Antonio.

Water Supply and Irrigation Papers.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside cover of this page.

Survey bulletins can be obtained only by prepayment of cost as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phoenix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier.
8. Windmills for irrigation, by E. C. Murphy.

In preparation:

9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker.
11. River heights for 1896, by Arthur P. Davis.
12. Water resources of southeastern Nebraska, by Nelson Horatio Darton.

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896-97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896; Stat. L., vol. 29, p. 453.)

The maximum number of copies available for the use of the Geological Survey is 1,000. This quantity falls far short of the demand, so that it is impossible to supply all requests. Attempts are made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules or donation of data. Requests specifying a certain paper and stating a reason for asking for it are attended to whenever practicable, but it is impossible to comply with general demands, such as to have all of the series sent indiscriminately.

Application for these papers should be made either to Members of Congress or to

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No. 9

IRRIGATION NEAR GREELEY, COLORADO.—BOYD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey and a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 355 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890, also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains a report upon the location and survey of reservoir sites during the fiscal year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 100 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell, quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 87, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation, No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892, quarto, 23 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a resumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part III, Irrigation, 1893, octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American engineering and engineering results of the Irrigation Survey," by Herbert M. Wilson; "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893, octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894, quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical condition and local peculiarities in each county

Fourteenth Annual Report of the United States Geological Survey, 1892-93, in two parts. Part II, Accompanying papers, 1894, octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W. J. Mead; "Natural mineral waters of the United States," by A. C. Peale; "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 9

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

X.C. Tarrner

UNITED STATES GEOLOGICAL SURVEY

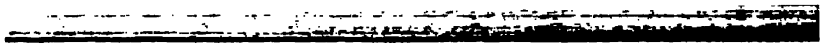
CHARLES D. WALCOTT, DIRECTOR

GATION NEAR GREELEY, COLORADO

BY

DAVID BOYD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897



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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, April 13, 1897.

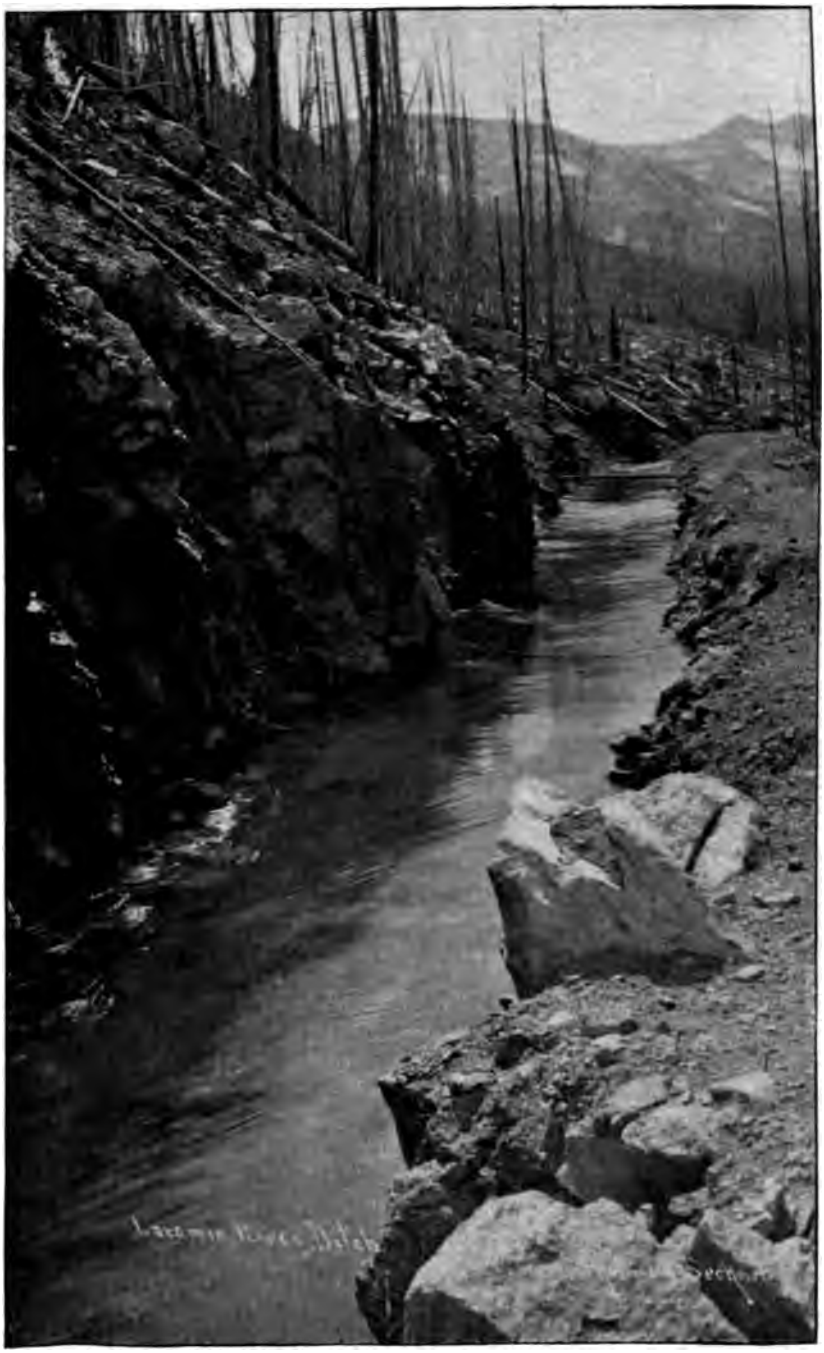
SIR: I have the honor to transmit herewith a manuscript entitled, "Irrigation near Greeley, Colorado," and to recommend that it be published in the series of water-supply and irrigation papers. The statements therein contained have been compiled from a report prepared by Hon. David Boyd, of Greeley, Colorado, one of the early members of Union Colony, which was led by Nathan C. Meeker and given encouragement and prominence by Horace Greeley. In a short paper of this kind it is impossible to go into the details of the struggles of this colony for existence and of the development of agriculture and of a system of water control whose leading features have been widely copied. The attempt has been made, however, to present the more prominent facts and those of most interest and value to the citizens of the West who are now following in similar paths and seeking to lay the foundations for broad and lasting systems of water utilization and control by which the rights of all may be determined and protected.

The paper by Mr. Boyd is prefaced by an introduction, compiled from the records of this division and from other sources, to illustrate the climatic and topographic conditions of Cache la Poudre Valley, in which Greeley is situated, and also the limitations of water supply, since it is upon the latter that the question of growth and development must rest. The evolution of systems for obtaining and applying water to the agricultural lands and of the complicated laws and regulations are in striking contrast to the quiet, almost imperceptible development of irrigation in southern New Mexico, to be described in the next paper of this series. A comparison of the two illustrates the great differences existing between various portions of our Western country and the impossibility of transferring local practices from one point to another irrespective of natural conditions.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



VIEW OF SKY LINE CANAL.

Taking water from the upper sources of the Big Laramie River and diverting it into the Poudre above Chambers Lake at the height or 8,000 feet

IRRIGATION NEAR GREELEY, COLORADO.

By David Boyd.

INTRODUCTION.

By F. H. Newell.

In the following paper by Mr. Boyd, a description is given of the growth and development of irrigation in the valley of Cache la Poudre Creek, in the northern part of Colorado. In this valley the best known town is Greeley, and hence this paper has been entitled "Irrigation near Greeley," as being most expressive of the location and character of the irrigation system and methods described.

Omitting the great Pacific Coast State of California, which lies for the most part outside of the strictly arid region, it may be safely claimed that Colorado stands preeminent in the extent and high degree of development of agriculture by irrigation. Here what may be termed American methods and devices for diverting and applying water to the fields have grown up, and the success attained has stimulated attempts elsewhere throughout the Western third of the United States. The same relation that Colorado holds to the rest of the arid region is borne by the Cache la Poudre Valley to the State of Colorado. It has for many years led in the construction and extension of irrigation systems, and its history may be said to epitomize the record of struggles and successes throughout the State.

The development of irrigation is not merely the result of a succession of victories over physical or material obstacles. In our country these form but a part—and, unfortunately, often a relatively small part—of the difficulties encountered by the irrigator. By far the most vexatious and expensive impediments to be removed have been those arising from the inapplicability of our laws and customs to the conditions prevailing within the arid region. Every instinct acquired through generations of life in a humid country seems to rebel against the methods of the irrigator, and every tradition of law is in direct opposition to the proper employment of the natural waters. These instincts and traditions have had to be laboriously demolished, usually after severe struggle, and the series of contests appears a never-ending one. There is little doubt that if it were possible to sum up

in one column the total expense incurred in the irrigation and reclamation of the West, and in another column the costs due to defective legislation, and especially to controversies over conflicting water rights, the latter would prove to be far the larger.

As in the development of her water resources Colorado has led the greater part of the West, so in the attempts to effect a suitable judicial and executive system having to do with water has this State been the pioneer. It can not be said that Colorado has been the most successful, for newer States, notably Wyoming, profiting by her experience, have achieved what seem to be more perfect systems; but their happiness in this regard is due largely to exertions of citizens of Colorado.

In the same way that Colorado has led in improvements in legislation have the citizens of Greeley and vicinity been the leaders in Colorado. First to experience the necessities, they have been at the front in urging needed reforms, and in these they have been notably successful. Thus it is appropriate in a series of papers devoted mainly to irrigation to review at some length the conditions near Greeley, for from here have come many initiatives to a proper state of affairs.

Considerable space is devoted in this paper to matter which at first sight may seem to be more peculiar to the lawyer than to the farmer, but, as above stated, the irrigator is called upon probably more than any other agriculturist to consider his legal environment. Although a beginning has been made, yet many years must elapse before the laws relating to irrigation, both State and national, fully recognize the necessities of the irrigator or permit such a development that the greatest good shall come to the greatest number. In a government by the people and for the people it is essential that every man become to a certain extent familiar with such defects before they can be remedied, as well as with the physical possibilities and limitations of his country.

There is no way in which these matters can be brought more clearly to the attention of the voter and farmer than by relating the experiences of other men in their struggles for existence. In nearly every State there are still to be made great and even fundamental changes in the laws relating to the control of water before the water resources can be fully utilized. The perplexities and even the mistakes of the pioneers teach most valuable lessons, for in many other States these conditions are not yet outgrown. Happy will their citizens be if they can utilize the costly experience of others without paying the high price.

LOCATION AND TOPOGRAPHY.

The State of Colorado comprises within its limits the headwaters of both the North and South Platte, the Arkansas, Rio Grande, San Juan, Grand, and White rivers. For convenience of water adminis-

tration, the State has been divided, as described on a later page, into six great divisions, corresponding to these large drainage basins indicated on the map (fig. 1) by roman numerals. These in turn have been divided into districts, and numbers have been arbitrarily assigned to these, as shown by the map. Of these districts, the one discussed in this paper is numbered 3, and includes Cache la Poudre Creek, one of the principal tributaries of South Platte River.

On the map the outlines of the water districts are indicated by light broken lines and those of the large divisions by heavy dotted lines. These latter follow the mountain summits or main divides, the line between divisions Nos. I and II and those to the west being

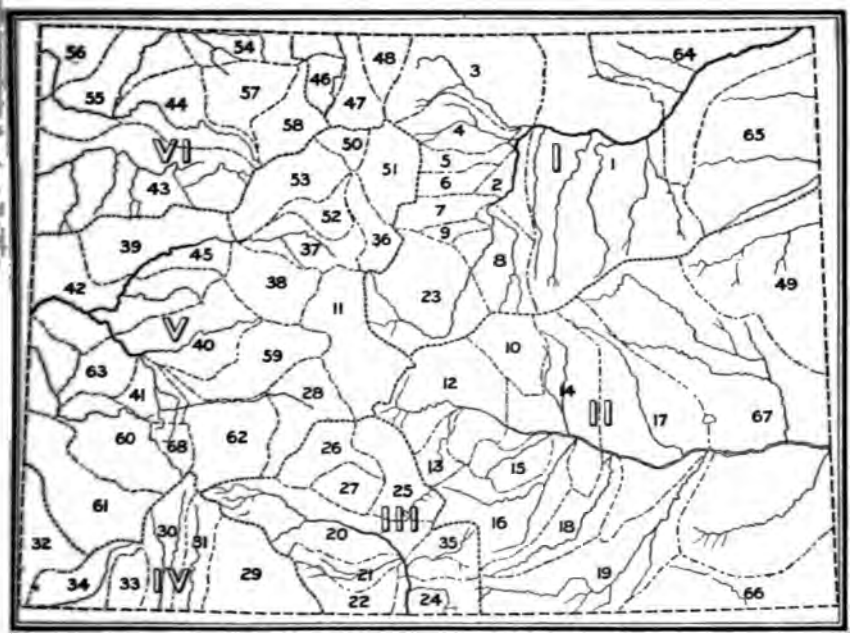


FIG. 1.—Map of water divisions and districts of Colorado.

along the continental watershed. This line thus marks the higher mountain ranges, which rise to altitudes of from 9,000 to over 13,000 feet. From these high crests the streams flow in all directions, those upon the east uniting to form the Arkansas, or, north of this, the South Platte. The latter stream, after debouching from its canyon some 12 miles south of Denver, pursues a nearly northerly course until it reaches Cache la Poudre Creek, some 52 miles by rail north of Denver and 4 miles east of Greeley. Near Denver it receives, from the mountains to the west, Clear Creek; 30 miles farther down, the St. Vrain; and 10 miles still farther, the Big Thompson. Cache la Poudre Creek is the last perennial tributary received by South Platte River before it joins the North Platte in Nebraska. The name,

originally Cache a la Poudre, signifies hiding place for the powd
In local usage it is often still further shortened to Poudre Creek.

These tributary streams above named head some 75 or 100 mi
back of the foothills among mountain peaks many of which are o
14,000 feet high. Their flow is small during the seven months of
year commencing with September and ending with March. The
charge of the larger ones during these months rarely exceeds
second-feet or falls much below 50.

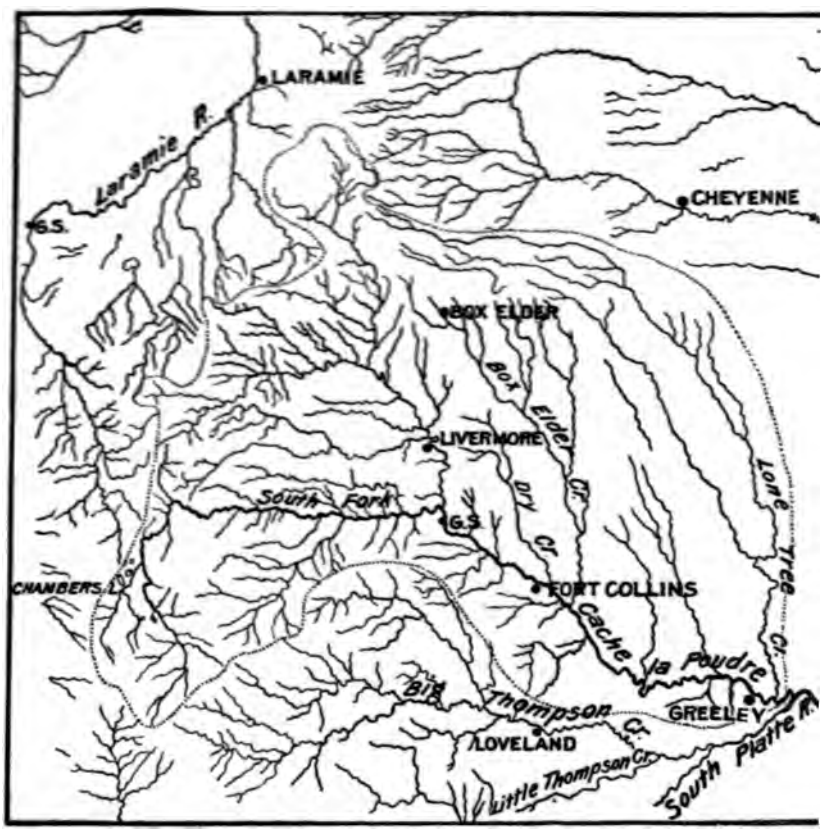


FIG. 2. -Map of Cache la Poudre Valley.

A small map, fig. 2, shows the principal streams and drain
channels tributary to Cache la Poudre Creek, and also exhibits
relative position of the towns. On the west the drainage basin exte
well into the high mountains, from which a considerable proport
of the rain and snow falling upon the steeper slopes escapes to
stream. In the center of the basin is the belt of foothill region, a
in the eastern third the undulating area, neither plain nor footh
From this come a considerable number of drainage lines, the prin
pal of which are Boxelder and Lone Tree creeks. These and otl

channels rarely receive water. For the greater part of the year their beds, though well-marked features, are dry; but after heavy rains or unusual rain storms—locally known as "cloud-bursts"—they become filled with raging torrents, which destroy everything in their paths. The configuration of the country is such that the canals from the perennial streams must cross these, necessitating considerable expenditure in the construction of flumes or in annual outlay for repairs. A glance at the map of these channels and of the canal lines crossing them shows the well-marked trend toward the southeast and indicates that any excess or seepage water brought by the canals or by torrents, whether flowing above ground or percolating beneath, must ultimately reach Cache la Poudre Creek at points not far from its mouth.

The streams on the western side of the basin flow with rapid fall through narrow valleys. At the point marked on the small map (fig. 2) with a dot and the initials G. S. (gaging station) the river leaves the canyon and enters upon a comparatively broad valley. To the north of the stream the lands below this point are low, the bottoms varying in width from half a mile to 2 miles. Above these are in succession two or three well-defined terraces or benches, as they are sometimes called. The soil and subsoil of these are, as a rule, coarse and pervious, being composed largely of sands and gravels. On the south of the river the valley lands are narrow and restricted, comparatively small areas being available for agriculture.

The distance from La Porte, where Cache la Poudre Creek enters the foothills, to its junction with the Platte is about 32 miles as the railroad runs. It is some 8 miles from La Porte to the gaging station at the mouth of the canyon. From the canyon to Chambers Lake it is about 70 miles by the road as it winds among the mountains. This lake is near the head of the Middle Fork and is fed by a number of small streams, the altitude of the lake being about 9,000 feet.

RAINFALL.

The soils of the valley lands are, as a rule, fertile and adapted to the production of crops of the temperate zone; but the rainfall is usually deficient in amount, and can not be relied upon to supply sufficient moisture to the fields. Agriculture is therefore possible only by means of irrigation, which has been developed to a high degree of efficiency, although falling far short of ideal conditions. The amount of rainfall within the basin of Cache la Poudre Creek has been measured for only a comparatively short time and at a few places, these being at the towns in the lower part of the valley. To the northeast of the basin a series of measurements have been carried on at Cheyenne, Wyoming, and to the south observations have been had at a considerable number of points, these being mainly at the foothill towns.

The principal rainfall stations in geographic order from north to

south are as follows: Cheyenne, Wyoming; and Boxelder, Livermore, Fort Collins, and Loveland, Colorado. To the east of these latter is Greeley, at the lowest point in the valley. The locations of these places are shown on the small map (fig. 2). The mean annual rainfall at Cheyenne, the elevation of which is about 6,100 feet, has been from 1870 to 1896 a trifle over 12½ inches; the minimum rainfall, that of 1876, was 5.03 inches, and the maximum, that for 1883, was 19.24 inches. The distribution by years is shown on the accompanying diagram (fig. 3), which exhibits by the height of the black columns the quantity of rain for each year from 1870 to 1895, inclusive.

The record of precipitation at Boxelder is comparatively short, extending only from 1890. The average annual precipitation since that time has been a little less than 16 inches. At Livermore the record is fragmentary, the average from 1889 to 1893 being about 14 inches. At Fort Collins the record is longer, beginning in 1872, but

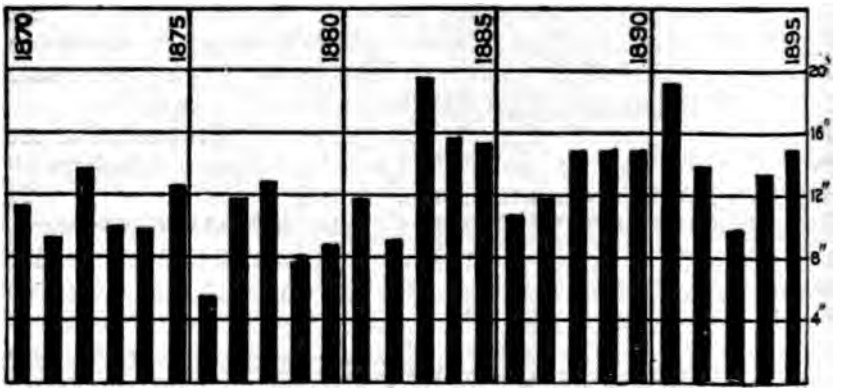


FIG. 3.—Diagram showing annual rainfall at Cheyenne, Wyoming.

is greatly broken until about 1887. The annual average has been 14 inches. The irregularity of distribution of the precipitation is well illustrated by the diagram in Pl. II, showing the monthly precipitation for the years 1887 to 1896, inclusive. This exhibits, by the height of each column, the total amount of rain occurring during the month, shown by the lettering at the top of the diagram. The greatest rainfall in any one month was that of May, 1892—4.83 inches. This diagram exhibits the usually heavy rainfall during the early summer and the prevailing winter drouths.

The record of rainfall at Loveland begins in 1887, being fragmentary until 1891. The average annual precipitation has been about 12 inches. At Greeley a less amount of rain is indicated, the average from 1887 being under 11 inches.

The following table allows a comparison since 1887 of the annual rainfall at the five points where the record is longest. The figures included in parentheses are those for which an interpolated value has

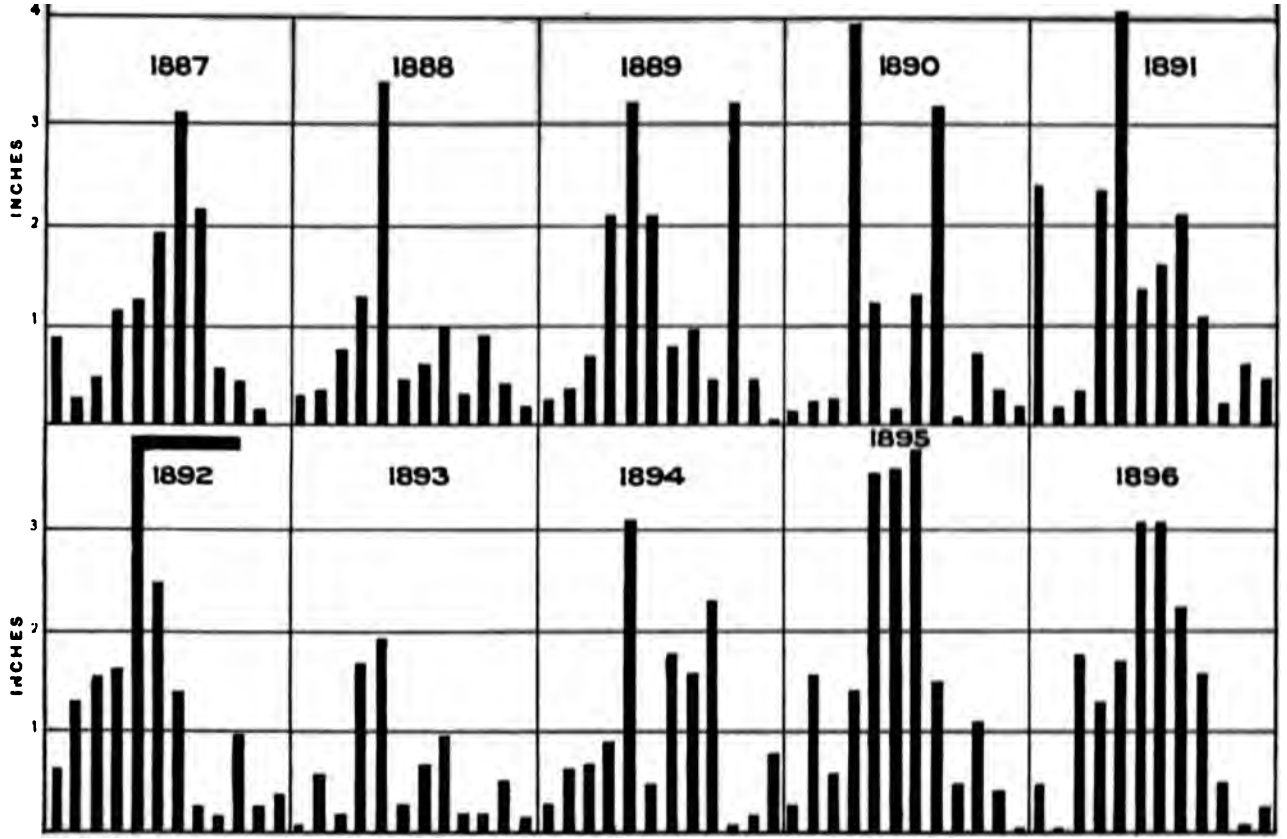


DIAGRAM OF MONTHLY RAINFALL AT FORT COLLINS, COLORADO.

een used for one or two missing months. The means given at the ottom of the table are not the averages of the figures above, but are he total of the monthly means, including thus portions of years otherwise defective:

Annual rainfall, in inches, within or near Circle in Powder Basin.

Year.	Cheyenne.	Boreiler.	Fort [illegible].	Loveland.	Greeley.
1887	11.82	.....	12.12	.....	.....
1888	14.71	.....	9.79	.....	.....
1889	14.65	.....	14.45	.....	14.38
1890	14.47	11.71	11.41	.....	.....
1891	18.97	20.45	17.70	.....	.....
1892	14.70	14.07	13.47	13.08	.....
1893	9.22	.....	7.06	7.03	5.04
1894	12.98	.....	12.06	10.77	9.93
1895	14.76	19.83	18.07	16.17	.....
1896	20.73	17.83	15.76	.....	13.52
Mean	13.62	15.88	14.00	12.13	10.71

The distribution of the rainfall by seasons is somewhat irregular, he greatest amount occurring during the months from April to ugust inclusive, nearly two-thirds of the total amount for the year alling at that time. This fact is illustrated by the following table howing the mean monthly precipitation at six important stations, the gures being obtained by averaging the records for all of the months uring which observations were kept. In the column on the right hese have again been averaged and computed in parts per hundred o still further illustrate the distribution by months: for example, the verage of these records for the month of May, assuming that they ll have equal weights, shows that 19.6 per cent of the total precipiation for the year has occurred during that month, or, in other words, ne-fifth of the total amount of rain fell at that time. Next to this omes July with 13.6 per cent of the total precipitation of the year. Next in quantity of rain stand April and June, these being approximately equal.

Mean monthly precipitation at specified stations in Colorado.

Month.	Cheyenne.	Boxelder.	Livermore.	Fort Collins.	Loveland.	Greeley.	Per cent.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	
January	0.49	0.84	0.92	0.70	0.29	0.20	4.32
February	0.42	0.54	0.56	0.56	1.04	0.41	4.43
March	0.78	1.33	0.72	0.80	0.88	0.50	6.28
April	1.47	1.26	1.86	1.73	1.43	1.57	11.69
May	2.22	3.30	2.86	2.92	2.75	1.88	19.96
June	1.55	1.77	1.80	1.67	1.12	1.38	11.66
July	1.90	2.22	1.03	1.85	1.83	1.59	13.06
August	1.54	2.14	1.34	1.32	0.29	1.04	9.62
September	0.97	1.06	0.64	0.92	1.09	0.54	6.55
October	0.69	0.64	1.92	0.90	0.82	0.68	7.09
November	0.32	0.41	0.41	0.42	0.28	0.76	3.26
December	0.27	0.37	0.17	0.30	0.36	0.16	2.04
Total	12.62	15.88	14.23	14.09	12.18	10.71	100.00

WATER SUPPLY.

The principal source of water supply for the agricultural lands near Greeley is Cache la Poudre Creek, a comparatively small amount being derived from wells and from the impounded storm waters of intermittent tributaries. The main stream has been measured at the point where it leaves the canyon above Laporte, the observations having been continued for a longer number of years here than on any other stream in the arid region. The record therefore has a peculiar value, giving the fluctuations of discharge through a series of years. The position of the gaging station is shown on the small map (fig. 2) by the dot marked G. S. (gaging station). This is above nearly all of the irrigating canals and ditches, the principal exception being the North Poudre Canal, which irrigates about 4,000 acres, mainly in the valley of Boxelder Creek. The drainage area above the gaging station, as measured by planimeter on the Land Office maps of Colorado and Wyoming, is 1,060 square miles,[1] a region mainly mountainous in character.

By one of the provisions of an act of the general assembly of the State of Colorado, approved March 5, 1881, the office of State hydraulic engineer was created, and this officer was empowered to make measurements of the waters of streams used in irrigation. Under this act Mr. J. S. Greene was employed to make measurements of Cache la Poudre Creek, a station being established in Marsh Canyon.[2] From

[1] The area given in the second biennial report of the State engineer of Colorado, p. 91, is 972 square miles, as measured on Hayden's drainage map of Colorado.

[2] First report of the State engineer, Eugene K. Stimson, of Colorado, for the years 1881 and 1882. Denver, 1882, p. 16.

lis measurements computations were made of the daily discharge rom June 20 to August 5. It was found, however, that the act was lefective, and further measurements could not be made until a emedy was provided. During 1882, therefore, no further attempt ras made to ascertain the flow of the stream.

Early in 1883 a site for a gaging station was selected on what was nown as McBride's preemption, about one-half mile above the mouth f the canyon and 12 miles above Fort Collins. The bowlders were emoved by blasting, and the channel was cleared out and straightened s well as was found possible with small expenditure. Gage read-ıgs were continued during the irrigation season, and occasional easurements were made of the velocity by means of an eight-vaned teley meter, manufactured by Buff & Berger, the instrument being rovided with an electrical registering device. After the completion ! work at the river station all of the ditches taking water from Cache , Poudre Creek in which measuring flumes had been built were tamined and computations were made as to their capacities at vari-ıs heights of water.

In the fall of 1883, after the river had subsided, a remeasurement as made of the cross section of the channel, and it was found that ıis had changed so greatly as to vitiate the original computations, lthough these had value as approximations. Propositions were ıade to the ditch owners taking water from this river that they fur-ish the necessary funds to build a permanent measuring flume where self-recording nilometer could be installed. By volunteer contri-utions the sum of $1,650 was obtained and used in the construction f a measuring flume and small house for sheltering the instrument. hese preparations were completed in November, 1883. In March of ıe following year the nilometer was placed in position and measure-ents of velocity were begun. It was found necessary to use for this urpose a stouter instrument, as the stream was of the character of a ırrent, carrying at times a considerable amount of drift. The instru-ent devised, known as the Colorado current meter, has been in suc-ssful operation for many years in the turbulent waters of that State.[1]

The record was continued through the season of 1885 and 1886.[2] It as noted at that time that the river has, in common with all moun-ain streams, a daily variation quite marked from the first of May to ıe last of October. This is due to the rapid melting of the snow in ountains under the influence of the sun during the daytime and ıe cessation of such melting at night. The greatest variation nounted to about 8 inches, or a difference of 1,500 second-feet.

[1] Second Biennial Report of the State Engineer of Colorado (E. S. Nettleton), for the years 3 and 1884, pp. 6-8. The daily discharge was computed from March 15 to October 16, 1884. ıe results are shown on pp. 84-91. Those for 1883 were not printed.

[2] Third Biennial Report of the State Engineer of Colorado (E. S. Nettleton), for the years 5 and 1886, pp. 55-57. The daily discharge was computed from April 14 to October 10, 1885, d from April 27 to October 17, 1886, pp. 62-66.

During May the point of maximum discharge was reached about 4 a. m. and the minimum about 7 p. m., the time becoming later as the season advanced. By the last of July the maximum flow was at 1 p. m. and the minimum at 3 a. m. Occasional storms also increase the volume of the stream rapidly, that on the night of May 20, 1884, causing it to increase in volume from 3,153 second-feet to 6,848 second-feet in eight hours. On August 18, 1884, the river rose a height of nearly 5½ feet in thirty minutes, subsiding almost as quickly.

The results of the measurements and computations made during 1887 and 1888 were not given numerically, but are expressed graphically.[1] For the succeeding years, 1889 and 1890, the station was maintained in part by the Division of Hydrography of the United States Geological Survey. About that time the station was found to be in poor condition, the plank flooring, resting on piling, having become bulged and

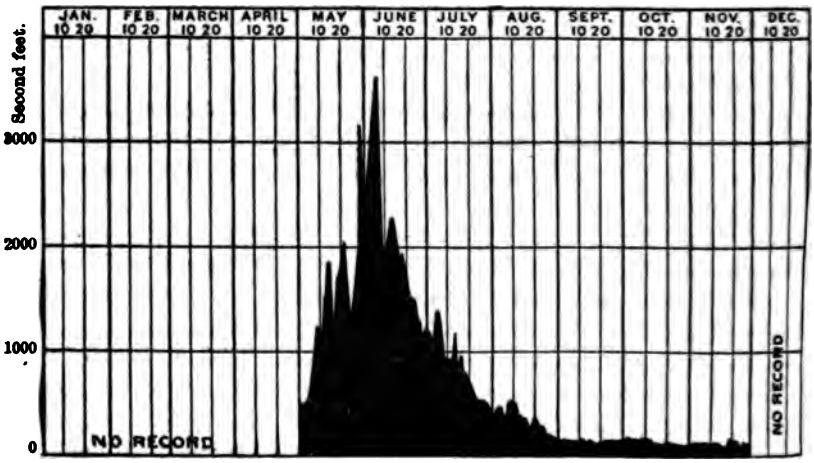


FIG. 4.—Diagram showing daily discharge of Cache la Poudre Creek for 1894.

rotted, so as to necessitate its removal. The walls of timber and plank gave way, resulting in gradual change of the cross section. Thus the results did not possess the accuracy possible while the section was in good order.[2]

On June 9, 1891, a heavy flood in the river, occasioned by the breaking of Chambers Lake dam, destroyed the registering apparatus belonging to the State of Colorado, and another instrument was substituted by Prof. L. G. Carpenter, of the Agricultural College at Fort Collins.[3]

[1] Fourth Biennial Report of the State Engineer of Colorado (J. S. Greene) for the years 1887 and 1888, in two parts; Pl. XV.

[2] Fifth Biennial Report of the State Engineer of Colorado (J. P. Maxwell) for the years 1889 and 1890. The results of computations of daily discharge for 1889 are given on page 22 and those for 1890 on page 23.

[3] Sixth Biennial Report of the State Engineer of Colorado (J. P. Maxwell) for the years 1891 and 1892, p. 18. Results of the computations of daily discharge for 1891 are given on page 22, and those for 1892 on page 23. Also, see Colorado Agricultural Experiment Station Bulletin No. 22, *Preliminary report* on the duty of water, L. G. Carpenter, p. 22.

During 1893 and 1894 the flow of water was reported at the weir in the canyon by the automatic register. The results are given in the progress report of the Division of Hydrography.[1]

During the succeeding years, 1895–96, occasional measurements were made under the direction of Professor Carpenter, but the results have not been made public.

DAILY MEAN DISCHARGE OF CACHE LA POUDRE CREEK.

The following tables of daily mean discharge of Cache la Poudre Creek have been arranged by months for convenience of comparison of the amount flowing in different years. The figures have been obtained from the following sources:

1881. First Biennial Report of the State Engineer, p. 16. Discharge computed from June 20 to August 5, 1881.

1882. No measurements were made during this year.

1883. Figures not published, but found in manuscript in the office of the State engineer. The discharges from March 23 to May 3, 1883, are only approximate, being obtained by interpolation, assuming that the cross section did not change. From May 4 to July 4, 1883, the discharges are deduced from gage reading and are claimed to be close approximations. From July 4 to August 20 the amount of decrease was assumed to be two-thirds of the amount of decrease per day from July 20 to August 20.

1884. Second Biennial Report of the State Engineer of Colorado, pp. 6–8, 84–91. Discharge computed from March 15 to October 16, 1884. Figures are also given in the Third Biennial Report, on pages 61 to 67.

1885. Third Biennial Report of the State Engineer, pp. 62–68. Discharge computed from April 14 to October 10, 1885.

1886. Third Biennial Report of the State Engineer, pp. 62–68. Discharge computed from April 27 to October 17, 1886.

1887. Fourth Biennial Report of the State Engineer. Figures not published. Diagram on Pl. XV. Discharges shown from March 18 to October 23, 1887.

1888. Fourth Biennial Report of the State Engineer. Figures not published. Diagram on Pl. XV. Discharges shown from March 14 to October 23, 1888.

1889. Fifth Biennial Report of the State Engineer, p. 22. Discharge computed from January 1 to December 31, 1889.

1890. Fifth Biennial Report of the State Engineer, p. 23. Discharge computed from January 1 to December 31, 1890.

1891. Sixth Biennial Report of the State Engineer. Discharge computed from January 1 to December 31, 1891.

1892. Sixth Biennial Report of the State Engineer, p. 23. Discharge computed from January 1 to April 17, and from May 18 to August 16, 1892.

1893. Progress Report, Bulletin United States Geological Survey, No. 131, p. 31. Computations from May 11 to August 31, 1893.

1894. Progress Report, Bulletin United States Geological Survey, No. 131, p. 31. Computations from May 2 to November 30, 1894.

1895. Progress Report, Bulletin United States Geological Survey, No. 140, p. 112. Mean monthly discharge only.

1896. Preliminary figures for May and June. By L. G. Carpenter.

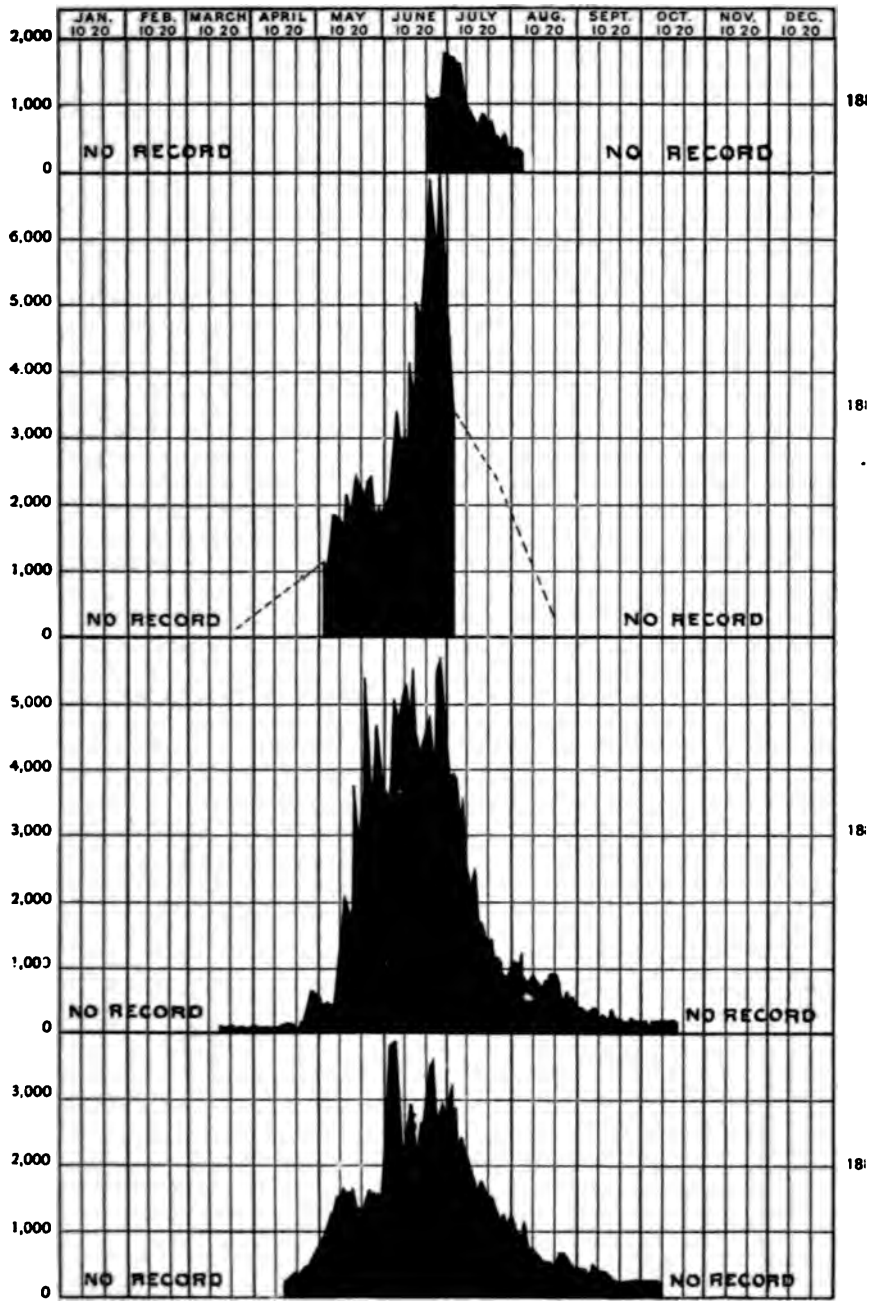
[1] United States Geological Survey Bulletin No. 131. Report of progress of the Division of Hydrography for the calendar years 1893 and 1894, p. 31.

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the months of January and February.

Day.	January.				February.			
	1889.	1890.	1891.	1892.	1889.	1890.	1891.	1892.
1	71	45	86	70	73	104	131	98
2	130	65	83	65	75	133	118	98
3	130	69	61	54	86	137	109	98
4	89	78	50	50	101	133	100	104
5	111	101	50	52	98	104	89	104
6	115	101	46	52	92	78	83	104
7	98	83	44	50	92	75	66	112
8	83	75	46	54	122	75	63	104
9	108	59	52	60	133	89	66	112
10	98	78	52	60	130	107	66	112
11	134	86	66	60	108	104	68	122
12	173	98	76	60	111	98	68	122
13	193	104	76	58	101	86	68	115
14	193	101	78	58	75	78	66	128
15	183	101	86	54	69	73	66	128
16	173	101	109	50	71	85	57	128
17	164	78	109	50	83	75	57	128
18	168	78	112	54	108	73	57	128
19	243	81	145	56	75	69	57	134
20	306	78	131	63	89	49	59	125
21	324	75	131	72	101	43	66	112
22	342	78	131	72	101	52	71	109
23	255	83	145	72	134	49	73	109
24	164	92	131	72	150	37	68	112
25	146	73	131	72	198	49	83	112
26	118	73	141	72	198	44	86	128
27	89	78	115	72	173	52	86	128
28	118	83	83	72	142	69	83	134
29	108	89	88	83	.....	.....	.....	128
30	98	87	88	92	.....	.....	.....	.....
31	73	78	109	98	.....	.....	.....	.....
Average	155	82	92	64	110	79	76	116

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of March.

Day.	1883.	1884.	1888.	1889.	1890.	1891.	1892.
1	.....	.....	.....	125	89	70	128
2	.....	.....	.....	104	104	63	134
3	.....	.....	.....	86	101	59	134
4	.....	.....	.....	78	92	52	128
5	.....	.....	.....	73	78	50	122
6	.....	.....	.....	58	71	50	106
7	.....	.....	.....	55	67	55	98
8	.....	.....	.....	55	65	71	92
9	.....	.....	.....	52	71	73	94
10	.....	.....	.....	52	58	68	60
11	.....	.....	.....	40	49	66	60
12	.....	.....	.....	41	47	66	62
13	.....	.....	.....	41	52	61	72
14	.....	.....	110	41	52	55	72
15	.....	73	100	41	60	52	72



DIAGRAMS OF DAILY DISCHARGE OF CACHE LA POUDRE CREEK FOR 1881, 1883, 1884, AND 1885.

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of March—Continued.

Day.	1883.	1884.	1888.	1889.	1890.	1891.	1892.
16	.....	71	100	42	85	52	72
17	.....	67	110	44	104	54	40
18	.....	62	120	47	101	54	60
19	.....	64	150	44	101	57	72
20	.....	78	110	43	101	63	72
21	.....	92	110	43	101	73	72
22	.....	48	120	47	107	76	72
23	107	64	130	48	125	73	72
24	133	70	150	46	114	70	72
25	159	72	140	46	104	66	67
26	185	76	120	43	101	57	50
27	211	67	90	43	98	52	50
28	237	55	110	43	98	46	50
29	263	50	150	44	85	42	50
30	289	63	130	47	78	40	50
31	315	75	130	55	78	32	56
Average	211	68	120	54	85	59	78

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of April.

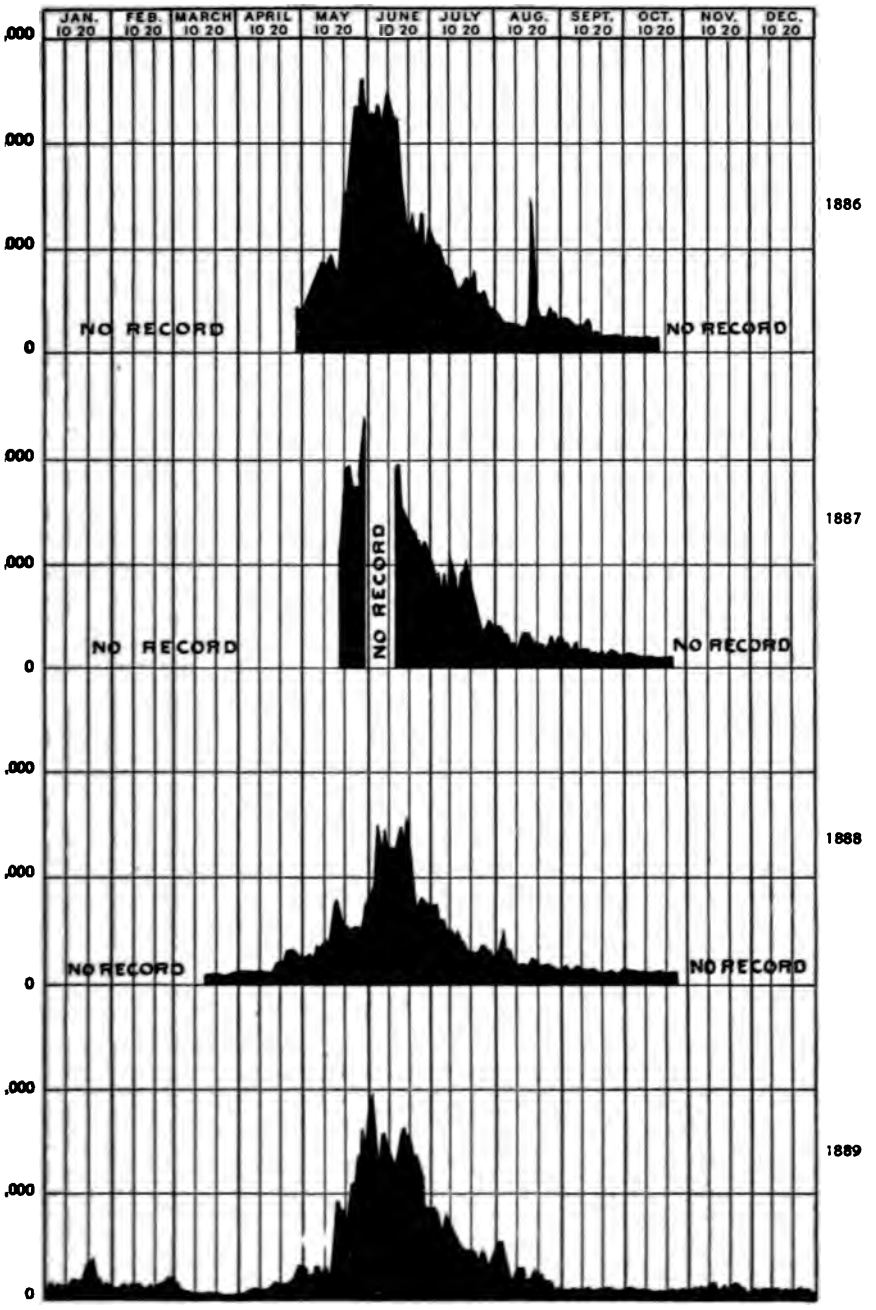
Day.	1883.	1884.	1885.	1886.	1888.	1889.	1890.	1891.	1892.
1	341	92	.....	.....	120	48	73	39	60
2	367	76	.....	.....	110	48	71	50	67
3	393	74	.....	.....	100	52	69	59	60
4	419	71	.....	.....	100	57	71	48	60
5	445	70	.....	.....	110	58	73	48	72
6	471	68	.....	.....	100	65	92	54	72
7	497	65	.....	.....	100	71	107	59	72
8	523	71	.....	.....	110	78	101	75	72
9	549	78	.....	.....	110	75	98	86	84
10	576	78	.....	.....	100	68	89	97	92
11	601	83	.....	.....	110	59	98	109	98
12	627	93	.....	.....	100	59	107	109	98
13	653	125	.....	.....	100	65	122	103	98
14	678	115	241	.....	100	70	137	81	98
15	705	120	250	.....	110	68	137	71	98
16	731	120	274	.....	120	73	133	68	112
17	757	122	284	.....	130	88	133	78	112
18	783	189	314	.....	160	129	141	134	.....
19	809	176	336	.....	170	122	178	166	.....
20	835	174	358	.....	190	101	237	166	.....
21	861	177	447	.....	220	101	243	159	.....
22	887	201	410	.....	330	101	271	159	.....
23	913	186	441	.....	350	101	300	194	.....
24	941	279	398	.....	330	107	336	214	.....
25	967	439	505	.....	340	146	455	258	.....
26	993	535	559	.....	350	198	474	296	.....
27	1,019	708	600	447	330	237	481	338	.....
28	1,045	702	624	416	310	288	435	323	.....
29	1,071	666	732	387	270	342	372	323	.....
30	1,097	602	822	369	260	312	306	344	.....
Average	718	219	447	405	181	113	200	144	84

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of May.

Day.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
1	1,111	501	954	404	.....	250	283	435	355	.....	.....	.....
2	1,149	453	1,029	466	.....	270	237	494	394	.....	.....	492
3	1,174	496	1,067	525	.....	290	214	552	441	.....	.....	481
4	1,049	521	1,165	581	.....	250	237	666	565	.....	.....	483
5	1,042	477	1,186	617	.....	280	282	764	806	.....	.....	572
6	1,352	508	1,237	654	.....	370	348	722	1,053	.....	.....	663
7	1,580	521	1,279	724	.....	390	324	633	1,160	.....	.....	760
8	1,848	671	1,258	772	.....	310	237	666	1,239	.....	.....	1,057
9	1,829	965	1,465	873	.....	330	237	729	1,179	.....	.....	1,239
10	1,707	1,387	1,488	900	.....	390	300	743	1,044	.....	.....	1,206
11	1,716	1,845	1,592	873	.....	400	254	830	823	.....	217	1,246
12	1,776	2,067	1,522	937	.....	350	254	836	908	.....	344	1,321
13	2,192	1,978	1,522	908	.....	360	397	800	710	.....	278	1,453
14	1,988	1,793	1,522	882	.....	460	736	729	766	.....	308	1,538
15	1,848	1,897	1,534	848	.....	550	903	736	710	.....	.....	1,829
16	1,942	3,491	1,557	805	.....	740	947	807	970	.....	.....	1,838
17	2,172	3,738	1,499	816	.....	790	888	888	1,092	.....	.....	1,355
18	2,399	3,576	1,420	937	1,150	650	851	1,078	1,130	276	.....	1,315
19	2,325	3,022	1,279	1,186	1,620	610	807	1,109	1,208	282	.....	1,697
20	2,201	3,375	1,290	1,465	1,910	550	736	1,186	1,250	278	.....	1,842
21	2,104	5,393	1,333	1,534	1,950	540	822	1,388	1,312	270	1,047	2,051
22	2,289	4,289	1,465	1,836	1,910	490	1,055	1,592	1,355	292	1,043	1,779
23	2,339	3,933	1,545	1,914	1,680	520	1,062	1,461	1,409	388	920	1,585
24	2,355	3,695	1,592	2,045	1,840	530	1,086	1,405	1,858	570	841	1,302
25	2,092	3,609	1,523	2,195	1,810	550	1,147	1,469	2,499	618	870	1,483
26	1,914	3,828	1,534	2,407	1,820	560	1,380	1,583	2,273	847	974	1,650
27	1,776	4,382	1,476	2,378	2,000	560	1,364	1,651	2,173	1,067	876	1,817
28	1,838	4,610	1,522	2,599	2,100	530	1,642	1,710	1,979	1,084	812	1,984
29	1,997	4,215	1,498	2,660	2,380	610	1,486	1,650	2,018	1,067	878	2,151
30	1,803	3,757	1,664	2,584	.....	750	1,477	1,510	2,044	1,075	1,107	2,318
31	1,928	3,637	1,965	2,250	.....	770	1,886	1,575	.....	872	929	2,485
Av.	1,833	2,536	1,419	1,308	1,847	484	770	1,044	1,224	642	763	1,390

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of June.

Day.	1881.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
1	.....	2,035	3,474	2,378	2,349	.....	880	1,960	1,736	2,005	750	.....	2,652
2	.....	2,091	3,598	3,355	2,307	.....	1,090	1,608	1,804	1,979	786	.....	2,820
3	.....	2,273	3,996	3,815	2,349	.....	1,350	1,502	1,625	1,790	1,112	.....	3,046
4	.....	2,400	4,493	3,815	2,422	.....	1,490	1,323	1,510	1,542	1,415	1,230	3,206
5	.....	2,468	4,835	3,858	2,392	.....	1,370	1,282	1,339	1,634	1,002	1,108	3,461
6	.....	2,802	5,064	3,390	2,264	.....	1,250	1,559	1,225	1,840	960	1,041	3,672
7	.....	3,050	4,914	2,706	2,293	.....	1,250	1,583	1,139	1,902	1,084	1,197	3,514
8	.....	3,386	4,785	2,335	2,407	.....	1,410	1,486	1,178	2,436	1,260	1,767	2,732
9	.....	3,050	4,854	2,230	2,509	.....	1,170	1,502	1,193	5,060	1,468	2,198	2,094
10	.....	2,880	5,196	2,236	2,584	.....	1,220	1,388	1,217	3,600	1,636	2,667	1,908
11	.....	3,067	5,177	2,614	2,509	.....	1,200	1,298	1,201	3,065	1,522	2,912	2,067
12	.....	4,142	4,894	2,989	2,378	.....	1,210	1,258	1,186	2,635	1,260	2,949	2,236
13	.....	3,771	5,135	2,925	2,278	.....	1,190	1,298	1,242	2,190	1,114	2,252	2,346
14	.....	3,688	5,459	2,799	2,278	1,970	1,260	1,307	1,225	1,860	1,200	.....	2,291
15	.....	4,183	5,248	2,524	1,993	1,970	1,420	1,559	1,282	1,728	1,457	.....	2,104
16	.....	5,006	4,720	2,293	1,784	1,770	1,450	1,608	1,315	1,624	1,360	.....	2,027



DIAGRAMS OF DAILY DISCHARGE OF CACHE LA POUDRE CREEK FOR 1886, 1887, 1888, AND 1889.

stimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of June—Continued.

Day.	1881.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
17	.....	4,783	4,553	2,321	1,704	1,590	1,320	1,486	1,331	1,501	1,658	.....	1,791
18	.....	4,798	4,318	2,599	1,580	1,520	1,360	1,518	1,339	1,373	1,444	2,386	1,915
19	.....	5,097	4,421	2,675	1,454	1,480	1,550	1,534	1,298	1,752	1,645	2,483	1,717
20	1,104	6,008	4,720	2,907	1,420	1,430	1,290	1,486	1,266	1,579	1,579	2,427	1,586
21	1,053	6,293	4,833	3,338	1,376	1,360	1,050	1,315	1,266	1,545	2,535	2,274	1,452
22	1,053	7,292	4,723	3,407	1,322	1,360	920	1,307	1,258	1,479	2,450	1,905	1,458
23	1,037	7,292	4,259	3,529	1,227	1,250	650	1,242	1,282	1,534	2,285	1,758	1,427
24	1,078	6,748	4,838	3,287	1,237	1,250	730	1,178	1,225	1,545	2,312	1,616	1,375
25	1,095	6,402	5,159	3,055	1,250	1,190	780	1,062	1,201	1,848	2,178	1,422	1,250
26	1,092	5,893	5,404	2,675	1,387	1,250	750	1,016	1,163	1,579	2,165	1,354	1,216
27	1,074	6,924	5,530	2,799	1,398	1,250	750	948	1,155	1,260	1,564	1,246	1,228
28	1,727	6,566	5,611	2,989	1,311	1,080	680	874	1,139	1,049	1,445	1,244	1,120
29	1,681	6,058	5,415	2,799	1,258	1,050	690	837	1,062	1,076	1,392	1,177	1,065
30	1,640	5,723	4,747	2,675	1,247	1,050	680	837	1,016	985	1,332	1,132	1,067
Average	1,239	4,539	4,812	2,911	1,876	1,401	1,114	1,339	1,280	1,900	1,512	1,815	2,063

stimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of July.

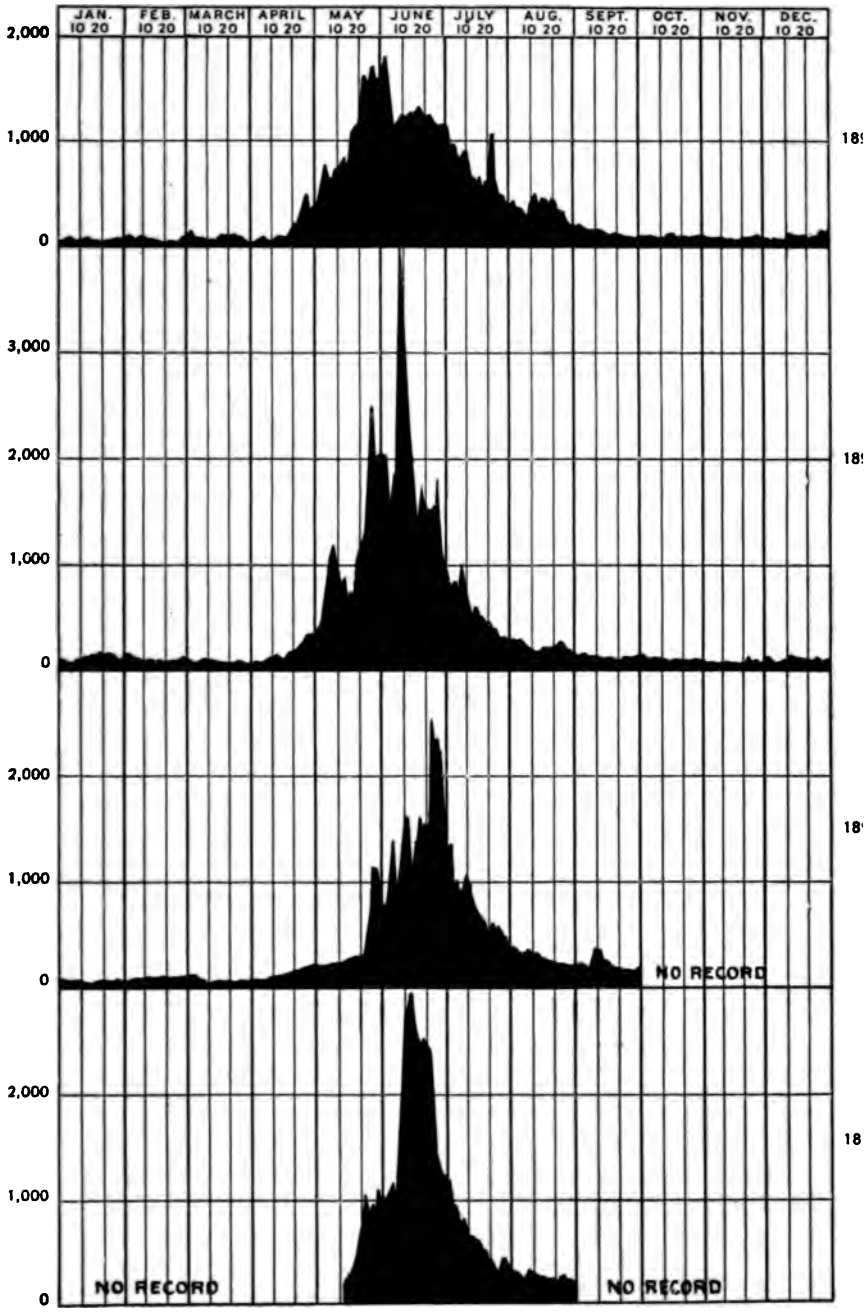
Day.	1881.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
1	1,622	5,082	3,852	3,055	1,176	980	670	844	970	784	1,392	1,144	1,109
2	1,600	4,447	3,970	3,186	1,126	900	690	844	963	849	1,340	1,038	1,082
3	1,600	3,988	3,845	2,878	1,057	920	610	779	957	864	870	996	1,109
4	1,582	3,395	3,848	2,890	1,038	880	560	722	896	824	1,020	997	1,273
5	1,510	3,344	3,459	2,890	1,038	720	550	633	852	768	993	947	1,234
6	1,507	3,294	3,309	2,321	972	700	540	579	822	832	950	795	1,158
7	1,393	3,243	3,581	2,349	927	700	490	680	764	1,003	908	840	1,078
8	1,203	3,193	3,572	2,378	873	880	560	757	736	907	984	833	956
9	1,084	3,143	3,180	2,208	839	700	510	757	857	768	1,084	744	925
10	963	3,062	2,575	2,181	831	1,260	490	736	770	699	1,000	693	925
11	853	3,042	2,360	2,019	764	890	470	653	712	626	960	663	923
12	786	2,992	2,218	1,939	700	830	450	599	601	558	857	678	936
13	740	2,941	2,305	1,888	685	740	510	546	590	531	822	661	1,177
14	680	2,891	2,458	1,784	639	710	420	513	546	524	784	602	878
15	635	2,840	1,933	1,688	609	940	410	461	613	512	736	608	982
16	673	2,790	1,753	1,712	602	900	350	435	533	492	698	576	899
17	845	2,739	1,755	1,762	609	960	330	416	481	462	648	526	782
18	823	2,689	1,622	1,676	692	1,060	320	397	515	432	639	511	817
19	814	2,639	1,522	1,652	707	890	310	385	559	426	564	476	820
20	713	2,588	1,428	1,557	669	810	290	366	559	415	530	454	728
21	715	2,513	1,462	1,522	764	710	280	354	1,000	392	584	401	696
22	585	2,438	1,198	1,476	596	580	300	294	1,023	381	558	384	647
23	522	2,362	1,194	1,398	552	510	350	378	613	354	512	359	602
24	547	2,287	1,145	1,258	545	490	390	390	502	322	538	348	567
25	481	2,211	1,123	1,176	588	420	380	336	448	302	493	353	561
26	564	2,136	982	1,206	539	420	340	312	403	283	443	444	567
27	528	2,061	955	1,176	466	410	330	295	403	278	402	463	553
28	484	1,985	903	1,076	441	490	310	271	360	288	396	406	522
29	396	1,910	862	1,155	410	450	310	306	348	307	380	383	497
30	376	1,834	1,026	1,145	404	440	260	416	336	307	348	354	461
31	361	1,759	1,063	1,076	393	450	270	448	366	298	342	343	444
Average	877	2,834	2,144	1,860	717	735	421	511	648	542	735	614	836

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of August.

Day.	1881.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
1	343	1,683	1,068	1,057	369	430	390	455	360	292	327	336	479
2	350	1,608	1,022	1,029	309	410	500	435	342	284	322	343	494
3	337	1,533	1,120	972	299	400	380	403	324	273	307	321	512
4	319	1,457	1,231	918	289	380	310	306	294	269	293	282	440
5	302	1,382	863	937	279	350	300	249	255	269	272	256	379
6	.....	1,306	849	1,116	264	330	280	209	222	251	268	251	396
7	.....	1,231	820	1,019	255	320	240	159	183	233	288	251	513
8	.....	1,157	772	856	255	260	220	146	173	212	271	293	487
9	.....	1,081	860	788	255	250	190	183	198	200	302	327	477
10	.....	1,006	934	772	250	220	180	231	336	200	288	298	464
11	.....	930	860	740	241	230	180	237	403	192	251	.....	427
12	.....	855	804	685	237	360	190	220	348	184	232	.....	393
13	.....	780	780	624	232	370	180	188	354	180	202	.....	362
14	.....	704	796	595	232	380	170	146	408	173	228	.....	365
15	.....	629	788	552	237	380	150	137	397	208	202	.....	369
16	.....	553	827	518	237	350	220	137	385	225	192	.....	347
17	.....	478	833	479	289	320	250	133	385	220	.....	.....	319
18	.....	403	916	466	1,476	280	210	154	306	233	.....	.....	298
19	.....	327	925	460	479	250	220	225	383	238	.....	239	295
20	.....	250	922	441	416	240	210	193	366	238	.....	189	282
21	.....	.....	800	559	343	250	160	178	348	242	.....	226	278
22	.....	.....	683	566	314	230	150	150	294	269	.....	218	271
23	.....	.....	590	559	294	220	160	146	271	288	.....	248	274
24	.....	.....	625	545	274	250	150	141	282	273	.....	219	240
25	.....	.....	653	518	416	320	150	141	251	229	.....	191	229
26	.....	.....	603	491	387	280	150	111	238	229	.....	161	212
27	.....	.....	625	466	342	260	140	98	234	220	.....	155	204
28	.....	.....	594	441	347	250	140	86	183	217	.....	158	179
29	.....	.....	511	416	325	320	140	81	178	192	.....	158	182
30	.....	.....	443	398	279	320	140	67	159	173	.....	141	165
31	.....	.....	423	389	264	320	140	71	150	155	.....	151	162
Average	330	968	792	657	338	307	213	188	290	228	265	235	175

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the month of September.

Day.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1894.
1	446	347	264	300	160	73	159	148	171
2	390	325	274	290	180	73	173	151	182
3	369	309	274	250	140	73	183	155	178
4	350	299	284	230	130	69	159	158	179
5	361	294	255	220	120	67	150	151	161
6	364	299	232	200	120	67	138	134	152
7	397	337	223	220	120	67	130	131	140
8	410	387	215	270	130	71	130	138	227
9	360	387	215	190	150	65	122	138	296
10	318	358	215	180	140	59	111	138	281
11	302	349	210	170	120	58	108	138	276
12	314	325	210	170	110	56	101	138	246
13	294	314	198	160	110	58	98	138	219
14	271	274	177	150	110	60	89	128	178



DIAGRAMS OF DAILY DISCHARGE OF CACHE LA POUDRE CREEK FOR 1890, 1891, 1892, AND 1893.

Estimated daily discharge, in second-feet, of Cache la Poudre Creek, etc.—Cont'd.

Day.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1894.
15	313	255	169	140	110	69	85	125	165
16	375	246	162	140	120	73	85	125	155
17	319	241	158	130	110	73	85	125	157
18	280	232	162	120	90	71	81	122	152
19	255	223	177	130	80	73	81	118	146
20	239	218	143	140	80	73	86	115	135
21	233	218	136	120	80	73	89	138	118
22	231	218	122	110	80	75	92	138	113
23	237	218	115	120	90	73	78	138	108
24	269	218	122	140	90	73	73	141	105
25	260	218	130	180	80	70	73	141	108
26	246	210	136	170	80	68	73	141	107
27	245	210	147	160	70	71	73	141	101
28	240	218	143	150	80	71	73	148	99
29	235	218	140	150	100	69	65	151	132
30	230	215	136	140	110	67	58	151	145
Average	305	272	185	175	103	69	103	138	164

Estimated daily discharge, in second-feet of Cache la Poudre Creek for the month of October.

Day.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1894.
1	225	210	133	120	100	71	57	151	144
2	212	206	133	150	110	73	55	148	158
3	203	202	140	150	90	69	55	145	135
4	197	202	130	140	100	69	58	128	141
5	203	202	133	130	110	71	60	131	118
6	199	202	133	110	100	71	73	134	146
7	199	202	130	110	100	67	73	141	151
8	212	202	133	120	110	61	73	134	143
9	209	202	133	130	100	56	73	122	128
10	215	206	130	120	100	55	73	115	131
11	202	.....	127	130	110	56	67	112	120
12	202	.....	122	120	100	60	89	112	107
13	197	.....	120	120	100	69	118	112	99
14	200	.....	120	110	110	68	118	112	94
15	200	.....	120	120	120	69	118	112	93
16	196	.....	122	130	100	65	101	112	93
17	.....	.....	130	150	120	65	80	115	93
18	.....	.....	.....	140	130	67	81	122	93
19	.....	.....	.....	150	120	69	81	112	89
20	.....	.....	.....	150	130	75	83	112	97
21	.....	.....	.....	140	100	73	83	112	82
22	.....	.....	.....	140	120	71	71	112	85
23	.....	.....	.....	150	130	69	73	115	87
24	.....	.....	.....	.....	.....	69	78	112	84
25	.....	.....	.....	.....	.....	69	78	109	84
26	.....	.....	.....	.....	.....	71	78	106	84
27	.....	.....	.....	.....	.....	73	89	107	78
28	.....	.....	.....	.....	.....	75	89	106	74
29	.....	.....	.....	.....	.....	86	89	104	71
30	.....	.....	.....	.....	.....	85	89	104	71
31	.....	.....	.....	.....	.....	92	92	104	78
Average	204	204	129	130	109	70	80	118	105

Estimated daily discharge, in second-feet, of Cache la Poudre Creek for the months of November and December.

Day.	November—				December—		
	1889.	1890.	1891.	1894.	1889.	1890.	1891.
1	92	89	100	79	69	67	84
2	71	83	98	91	78	60	95
3	75	81	98	96	67	61	72
4	86	78	95	.....	55	55	54
5	69	69	84	.....	56	52	60
6	71	67	84	.....	60	67	72
7	73	71	77	91	60	46	72
8	92	73	72	95	65	52	77
9	111	71	72	96	65	48	77
10	122	68	77	93	60	50	82
11	122	58	82	89	48	107	109
12	98	55	82	94	73	80	100
13	85	49	87	85	73	71	100
14	86	52	84	80	78	65	100
15	101	44	79	85	89	58	98
16	98	39	67	77	86	60	100
17	107	41	72	42	33	63	92
18	107	42	72	116	89	67	74
19	111	43	70	150	73	53	72
20	101	52	82	146	67	55	72
21	101	55	100	115	61	44	72
22	92	61	95	107	55	67	72
23	98	63	84	60	58	67	74
24	89	69	84	57	73	58	92
25	67	61	82	103	61	55	87
26	58	65	87	90	71	60	56
27	45	73	84	92	81	71	56
28	56	55	84	91	67	83	72
29	65	53	82	89	43	101	72
30	73	63	84	93	41	86	72
31	.....	.....	.....	.....	39	101	72
Average	87	61	83	83	64	65	79

Estimated mean monthly discharge of Cache la Poudre Creek from 1881 to 1894.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1881	.....	.....	.....	.....	.....	*a* 1,239	877	*b* 330	.....	.....	.....	.....
1883	.....	.....	*c* 211	718	1,833	4,539	2,834	*d* 968	.....	.....	.....	.....
1884	.....	.....	*e* 68	219	2,536	4,812	2,144	762	305	*f* 204	.....	.....
1885	.....	.....	.....	*g* 447	1,419	2,911	1,860	657	272	*h* 204	.....	.....
1886	.....	.....	.....	*i* 405	1,308	1,876	717	338	185	*j* 129	.....	.....
1887	.....	.....	.....	.....	*k* 1,847	*l* 1,401	735	307	175	*m* 130	.....	.....
1888	.....	.....	*n* 120	181	484	1,114	421	213	103	*o* 109	.....	.....
1889	155	110	54	113	770	1,339	511	188	69	70	87	64
1890	82	79	85	200	1,044	1,280	648	290	103	80	61	65
1891	92	76	59	144	1,224	1,900	542	228	138	118	83	79
1892	64	116	78	*p* 84	*q* 642	1,512	735	*r* 205	.....	.....	.....	.....
1893	.....	.....	.....	.....	*s* 763	*t* 1,815	614	*u* 235	.....	.....	.....	.....
1894	.....	.....	.....	.....	1,380	2,063	836	175	164	105	83	.....

a June 20-30, 1881.
b August 1-5, 1881.
c March 23-31, 1883.
d August 1-20, 1883.
e March 15-31, 1884.
f October 1-16, 1884.
g April 14-30, 1885.
h October 1-10, 1885.
i April 27-30, 1886.
j October 1-17, 1886.
k May 18-29, 1887.
l June 14-30, 1887.
m October 1-23, 1887.
n March 14-31, 1888.
o October 1-23, 1888.
p April 1-17, 1892.
q May 18-31, 1892.
r August 1-16, 1892.
s May 11-14 and 21-31, 1893.
t June 4-13 and 18-30, 1893.
u August 1-10 and 19-31, 1893.

SETTLEMENT IN CACHE LA POUDRE VALLEY.

During his tour in Colorado, in 1859, Horace Greeley was impressed with the belief that the higher lands were adapted to cultivation if irrigated. On his return to New York he discussed the matter, and with the cooperation of N. C. Meeker gave the proposition great publicity. The colony plan presented through the columns of the Tribune culminated in 1870 in the formation of Union Colony, which, settling in Cache la Poudre Valley, gave to their town the name of Greeley.[1]

When the colony arrived, it found a few settlers in the valley, who had occupied the bottom land mostly for the pasture and wild hay it offered. They had taken out from the Cache la Poudre Creek a number of small canals, which had in cultivation under them, as near as can be ascertained, about 1,000 acres. They generally believed that the higher bench land lacked fertility, and that it was extremely unwise on the part of the colony people to construct canals for its irrigation.

UNION COLONY.

Union Colony, under the leadership of N. C. Meeker and the auspices of Horace Greeley, undertook, in the spring of 1870, the settlement of the lower end of Cache la Poudre Valley, the headquarters being upon the site of Greeley. The leaders of the colony constructed, as quickly as possible after their arrival, a ditch on the south side of the creek, on the site of the one that now irrigates the lots in town and

[1] Second Biennial Report of the State Engineer of Colorado for the years 1883-84, p. 20.

the lands in its vicinity. There were only some 200 acres put into crops, but the ditch was small and poorly constructed, and without a dam at its head in the river to divert the low water into it, so that not enough water could be obtained for this small area.

This first ditch demonstrated the great fertility of the soil when sufficiently moist to enable vegetation to avail itself of its plant food. The original cost was $6,333. It was enlarged three times, in 1871, 1872, and 1873, and then cost in all, with dam, about $25,000. It has

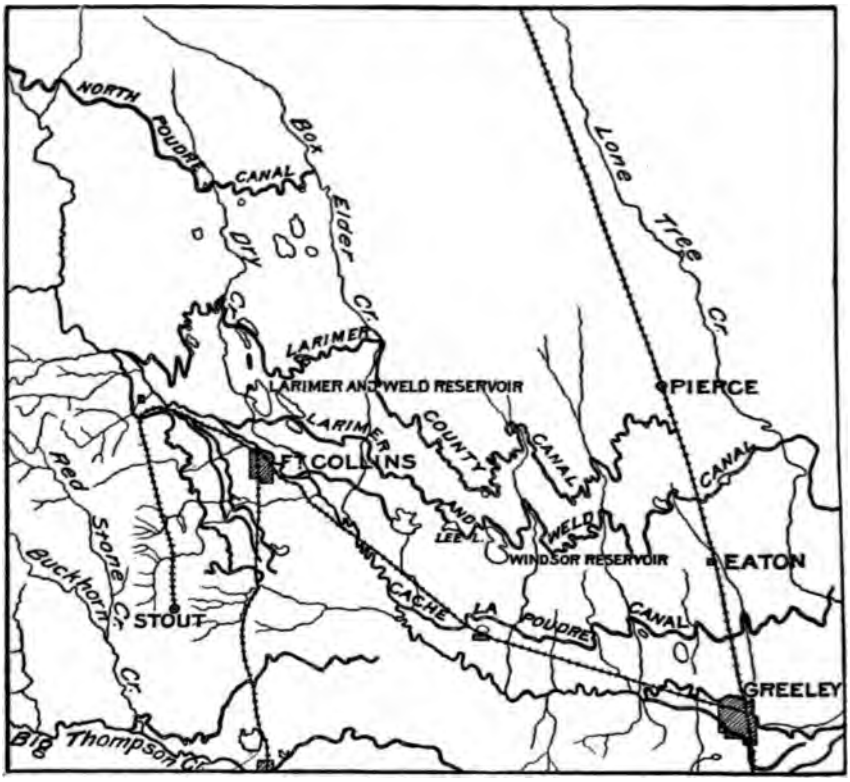


FIG. 5.—Map of canals near Greeley, Colorado.

a capacity, by the decree of the court, of 173 second-feet. In 1894, as shown by a table in the State engineer's report, it is credited with having only 1,275 acres under irrigation, of which 480 are reported as pasture and waste land. This, no doubt, leaves out of account the town lots irrigated from this canal, which have a probable area of 300 acres. The insignificance of the area thus reported as under cultivation shows that if this had been all the colony would have been a failure as an agricultural community, and there was no other industry for it in this locality to pursue.

CANAL AND RESERVOIR SYSTEMS.

A number of canal systems were projected by Union Colony, the first of these, or No. 1, never begun, being planned to head in the canyon above La Porte and terminate at Crow Creek, covering nearly all of the lands later watered by the two canals known as the Larimer County and the Larimer and Weld County canals. Canal No. 2, later known as Cache la Poudre Canal, was begun during the fall of 1870.[1] Canal No. 3 was the town ditch described above. No. 4 was to come out of Big Thompson Creek and water the lands on the bluff south of Greeley, now irrigated by the Loveland and Greeley Canal. Thus canals Nos. 2 and 3 were the only ones constructed under the original plans of the colonists.

A list of the most important canals and ditches is given on page 51 in connection with the crop statistics of this district. The location of the three largest is shown on the accompanying map (fig. 5) and a general description of them is given below. These, in geographic order, are Cache la Poudre Canal, immediately north of the city of Greeley; above this Larimer and Weld Canal; and still above, and in a general way parallel, Larimer County Canal. Still further to the northwest is also shown on this small map the lower end of North Poudre Canal, belonging to the North Poudre Land, Canal, and Reservoir Company, and described on page 58.

CACHE LA POUDRE CANAL.

The survey of what was originally known as Canal No. 2 was prosecuted during the summer of 1870, and the construction of its whole length—35 miles—was practically completed during the autumn of that year and the spring of 1871. It was supposed to be in shape to deliver an abundance of water to all the crops that could be got in under it for irrigation during the summer of 1872. Some 2,000 acres were put in crops, but most of them were burned up for want of water. It was a year of scarce supply, there was no dam in the river, and the head of the canal ran for a mile and a half along the edge of a slough upon which its lower bank rested, and this bank soon settled so that it could not hold the passing water. This loss of crops by the most enterprising and courageous colonists—men of moderate means—came near paralyzing the whole enterprise.

During the fall of 1871 and spring of 1872 an enlargement was made and a dam put in the river. The cost of the first construction was about $27,000 and of the enlargement $20,000 more. This year the river had an ample supply, and the spring was moist, and hence favorable for plowing and the germination of seeds. The result was an area planted of some 6,000 acres and fine crops. However, the canal was yet quite too small for the 25,000 acres of land under it

[1] History of Greeley and the Union Colony of Colorado, by David Boyd, 1890.

owned by colonists, and two other enlargements were made in 1874 and 1877, making the total cost up to that date about $87,000.

The Cache la Poudre Canal—originally Union Colony Canal No. 2—was the earliest of the large systems. It was for a long time deemed unnecessary to supplement its river supply by a reservoir. However, it was found that in more than one-half the years the river water gave out before the potato crop was made, and that the farmers under it were at a disadvantage as compared with those who had

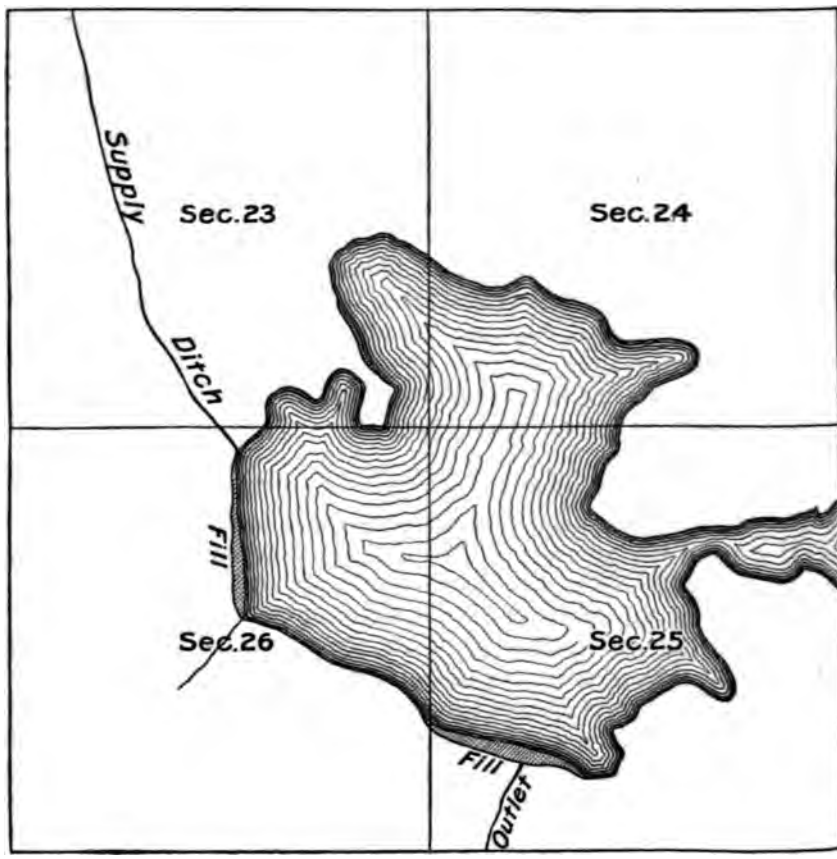


FIG. 6.—Map of Cache la Poudre Reservoir.

water from the Larimer and Weld Reservoir, the contents of which were used for the potato crop in 1891. In 1892 the farmers under the Cache la Poudre Canal commenced to take steps toward building a reservoir. They found a site (shown in fig. 6) about 4 miles above their canal, the contents of which could be emptied into it about 2 miles below its head, and could be filled by constructing a feeding canal some 8 miles long and heading in the river just below the tail-race of the Linden Flouring Mills, which enters the river at Fort *Collins.*

These mills have an early appropriation from the river, dating back to 1867, for 93 cubic feet per second. As this claim antedates the adoption of the constitution of the State by 9 years, the courts have decided that the provision in that instrument giving claims for water for irrigation purposes a superior right to those for mechanical purposes does not apply in this and similar cases. Hence the water of the river must be run to the head-gates of the mill canal, however low the river is, except for the use of the few canals that antedate it and whose heads are above the mill tailrace. Since none of the water is consumed in furnishing power to the mills, it does not affect canals below it. There is nominally a claim for 401 second-feet prior to its claim, but the heads of more than half of the ditches making the claim are below its tailrace and many of the others have been abandoned. The most important claim above its tailrace is that of 19 second-feet by the Larimer and Weld Canal, but this only antedates it for irrigation purposes; for storage purposes its reservoirs rest on their own date, which is 25 years later than that of the mills. The Pleasant Valley and Lake Canal also has a claim of 40 feet antedating that of the mills, and this heads above the mill power canal, and hence as long as irrigation lasts can take the water, and does in the autumn, when it is scarce, to the detriment of the mills. The same is true of Dry Creek Ditch to the extent of an appropriation of 12 second-feet.

While irrigation lasts these three claims greatly disturb the mill supply when the river is low, early in spring and late in autumn, and hence its proprietors put in steam power to use when water is scarce. Should they abandon the use of the water altogether, an interesting question will be raised concerning the legal rights of the Cache la Poudre Reservoir to the water which the position of its head-gates in the river just below the tailrace now allows it to store to the extent of what runs through the mill race, in spite of the fact that its claims to water for storage purposes postdate nearly all the other important reservoirs. These are all supplied by canals that head above the tailrace, and nearly all—and at times all—the winter supply of the river must be allowed to flow by for the mill, and hence for the sole benefit of the reservoir we are considering. The main reason for locating the head of their reservoir supply canal where it is was to obtain this very water, and now, if the mill should abandon its use, who would have the right to it? Should it be turned back into the river and be subject to the appropriation already made, or should this reservoir continue to enjoy the privilege?

Cache la Poudre Canal has been conveyed by Union Colony for a nominal sum to a new company, composed of the farmers owning the land and water rights under the canal. The new owners have expended about $25,000 in straightening the course of the canal (shown in Pl. VI), constructing permanent dam and head works, and putting in checks at the head of nearly every lateral. These were needed because the slope of 3.2 feet per mile was too steep for a canal

of this size and resulted in erosion of the bed and lowering of the channel. The head works are of stone masonry laid in cement. The gates are of iron, and each is constructed of an upper and lower section, only one of which is moved when the head at the gates is high, less power being thus required for lifting.

The duty of water under Cache la Poudre Canal has been computed by Prof. L. G. Carpenter.[1] The length of time during which this canal has been in operation and the consequent long experience of farmers render the measurements of considerable value for comparative purposes. The amount of water taken into the canal was measured daily or estimated from a record kept by an automatic register. The results given in the following table show a comparatively large duty if a long season is taken, but, on the contrary, for the month of June alone, when water is in abundance, the average duty drops off rapidly, falling to from 65 to 95 acres per second-foot.

Duty of water under Cache la Poudre Canal in acres per second-foot.

Period.	Days.	1890.	1891.	1892.
May 1 to September 1	123	132	153	112
April 1 to September 1	153	164	192	146
May 1 to November 1	184	198	232	176
June alone	30	72	95	65

The total cost of the canal has been $112,000. There are some 300 80-acre water rights held in the canal and represented by a share of stock for every 10 acres. Each is entitled to a proportionate share of the water in the canal at all stages. It will be seen that the average cost of an 80-acre right in the canal was $373⅓. Such rights, when the land under them has become so wet as not to need irrigation, have been selling to parties owning lands lately taken up at the lower end of the canal for $2,000 apiece. This price does not include a right to water from the reservoir, which is owned by another company, although most of its stock is held by the parties who own the canal. Rights to 80 acres in this reservoir were sold in 1896 for $800 apiece. Placing the cost of the reservoir at $120,000 and the number of rights at 300, the cost per right would be $400, apparently giving a profit of 100 per cent on the investment. Of course in all such enterprises for a while the capital invested is unproductive. In this case the period was not long, since the work was prosecuted with vigor, the reservoir being fit for use one year after its commencement. Those not owning land have generally been able to rent their reservoir rights at a fair interest on the investment.

[1] Colorado Agricultural Experiment Station Bulletin No. 22, Preliminary Report on the Duty of Water, pp. 18-21.

CACHE LA POUDRE RESERVOIR.

This is the most expensive of all the reservoirs in the valley. In the argument before the court the cost is placed at $125,000. The statement obtained from the company gives $28,643 for real estate for site of reservoir and right of way of supply canal, 8 miles long (capacity, 150 second-feet), and outlet canal, 4 miles long (capacity, 200 feet per second); also $81,623 for construction, making a total cost of $110,266. It has by far the longest and highest embankment of any of the reservoirs in the valley. At the outlet this embankment is 38 feet high, the height of water above the bottom being 30 feet. The breadth of the base at this place is 300 feet. The inside face has a slope of more than 3 to 1, and still the riprapping slides down each year on account of the action of the waves. When first laid it had a uniform slope from top to bottom, but now the slope is quite irregular, through the action of the waves moving the rocks and washing away the embankment under them. This is of good material, being largely composed of coarse gravel brought from a hill near one end by wheel scrapers. The rock for riprapping was brought from the foothills by rail to the nearest point, which is 2 miles off, and thence by wagon. It cost per ton, laid down, $110. It is medium-sized, flat sandstone, the refuse of the quarries where building and flagging stones are taken out.

The conduit is but a few feet deep below the level of the natural surface, the material of its foundation being a tenacious clay. The base is of wide flagstone laid on a grout bedding of gravel, sand, and Portland cement. The width is 5 feet inside, walls 2½ feet high, spanned by an arch 2½ feet high in center. There are two collar walls extending from the masonry of the conduit into the embankment, to prevent the water from working its way along the connection of the earth and masonry. It has shown no signs of weakness at this place, but when the reservoir is full the embankment gets quite soft throughout. However, it yearly gets less so. It settled 4 to 5 feet the first year after the water was turned in, although the teams had traversed it back and forth with wheel scrapers bringing the gravel and earth from the ends of the fill.

The gates and means of raising them are a novelty, the invention of Mr. Gordon Land. The front of the inlet of the conduit is a steep inclined plane, some 20° from the vertical. The aperture is divided into two sections by a timber running midway up and down in the plane of the incline, and on the outer edges of it are fastened iron plates of about the weight of wagon tire. A similar timber and tire are on each side of the aperture, thus forming a double track for two iron gates. These latter are each attached to two axletrees which

have wheels at their extremities and are brought to bear upon the track when the gates are being raised.

This is done by means of a wire rope, one end of which is attached to a cog-geared windlass placed on the top of the embankment and the other end to a lever attached to the axle of the gate, which axle is eccentric, so that the movement of the lever causes the wheels to bear on the tracks and to roll along it, instead of having the edges of the gate drag over the edges of the supports behind it, as in raising the ordinary gate. Each rope passes over a pulley placed at the top of the incline. It should be further said that the axle and wheels are attached to the upper and outer sides of the gates, and the front and rear axles are yoked together so that the rope acts on both and presses their attached wheels against the tracks in lifting the gates.

The cost of this reservoir equals that of the canal of which it is an adjunct. It furnishes only 5,654 acre-feet, while during the irrigation season of 1894 the canal drew from the river 70,610 acre-feet, or more than twelve times as much. Hence it is to be said that reservoir water is costly.

At present prices of farm produce it certainly does not pay to store water at this cost. Storage reservoirs, even of the most economical location, can not as a general rule be profitably employed in irrigation, except as adjuncts to canals that have for the most part their supply from a fairly permanent source during the irrigation season. None of the streams in this State except those of the western slope hold out in the latter part of the season so as to furnish water enough to complete the growth of certain crops, save for a few claimants of early rights. The one crop in this valley for which there is need of later water than the streams afford is potatoes. Up to 1895 this crop has been on an average profitable, even though we have been forced to seek a wider market than that of the plains and Rocky Mountain region. Hence the late development of reservoir construction in this valley.

It will be further noted that when a canal is already built, with all its laterals and means of distribution, and a reservoir can be constructed so as to deliver its water into it near enough to the head to supply the greater part of its customers, the case is very different from that of building a reservoir that has to provide all the means necessary for the distribution of its contents. This is the case of nearly all of the reservoirs in this valley. When that can not be done, the exchanges noted on another page effect the same economy so far as they can be brought into practice. When, however, the relation of the reservoir to the canal is like that of the one we are considering, it gives an independence and certainty not to be found where the use of the water by its owners depends upon so many contingencies.

As stated on a preceding page, the feeding canal for this reservoir

VIEW OF DAM AND HEAD GATES OF LARIMER AND WELD CANAL, POUDRE VALLEY.

heads in the river immediately below the tailrace of the Linden Mills, at Fort Collins. This location was made for the purpose of securing the water from this mill, as intimated above. The destruction of the mill has given rise to one of the most perplexing questions in regard to water rights. The mill in its use of water power has proved a great detriment to the irrigation of the valley, since in order to turn its wheels it has been necessary to allow the water to pass the head gates of all the canals feeding reservoirs except this one. The other parties in interest would undoubtedly have purchased the rights of the mill and turned the water back into the river to be used for storage in the order of its appropriation were it not for the claim of vested rights made by this lower reservoir.

Recurring to the value of this reservoir as an investment, it may be said that in spite of the comparatively early appropriation of water by the canal it would not be possible without it to obtain in two years out of three sufficient water for the potato crop. The number of sacks of potatoes produced under this canal in 1894 was 602,485. During that year the crop sacked was worth, on an average, 70 cents per hundredweight. Deducting 5 cents for the cost of the sack and 10 cents for harvesting, the net value is 55 cents. The seed and labor cost the same amount for a half as for a whole crop. We may set down to the credit of the reservoir one-half of this crop, which at 55 cents per hundredweight amounts to $165,683, or a third more than the cost of the reservoir. That, however, was an exceptional year, both as to product and price. It would be fair to estimate the average crop under this canal at 500,000 hundredweight, and the average price at 40 cents per hundredweight. Allowing one-half the crop as due to the reservoir water, this would amount to $62,500, or one-half the cost of the reservoir.

LARIMER AND WELD CANAL.

The Larimer and Weld Canal takes water from Cache la Poudre Creek above Fort Collins and about 12 miles above the head of Cache la Poudre Canal. The total length is stated to be 50 miles, and the average bottom width 25 feet. Water is diverted by a wing-crib dam 177 feet long and 4 feet above the bed of the stream.[1] The dam and head gates are shown in Pl. VII. This canal has under it one-third of all the land under ditch in the valley and has a capacity greater by one-fourth than that of any other. It can take in the average flow of the whole river except during the 60 days commencing with the middle of May. In Pl. VIII is given a view looking up the canal to the head-gates. Before its final enlargement, which was, in fact, its real construction, there was nominally appropriated 2,735.87 cubic feet per second, this being more than the average flow of the river for any one month. The older canals could not use so much water as this, but

[1] Report on Agriculture by Irrigation at the Eleventh Census. F. H. Newell, 1894, p. 135.

could take so much that during years of scarcity this canal could at no time receive a full head. Every year the supply fell to its second appropriation of 19 feet before the time to irrigate potatoes, which up to 1895 was the best-paying crop.

LARIMER AND WELD RESERVOIR.

An excellent site for a reservoir was found at a point a mile and a half north of Fort Collins, about a quarter of a mile above the canal and only 2 miles from its head. This could be supplied from two small canals above the Larimer and Weld, the bottom of the reservoir being only 2 feet above that of the canal. This site is a natural basin, in which, when filled to the lip of the lower rim, the surface of the water would be 25 feet above the bottom of the outlet, and which, it is estimated, would contain 350,000,000 cubic feet or 7,700 acre-feet. The canal company did not wish to undertake this work, but permitted the farmers who held contracts for water from it to take the site which it had surveyed. These farmers represented water rights covering 15,000 acres. They formed a company known as the Larimer and Weld Reservoir Company, proceeded to condemn the site and procure the means of feeding it.

The following are the principal items of expense and relate to construction to hold a depth of 25 feet:

Surveying and engineering	$2,870
Land and rights for water	13,768
Construction	21,796
Attorneys' fees	5,796
Court expenses	2,312
Miscellaneous	18,240
Total	64,782

It will be seen that only about one-third the expenses was for construction, not including surveying and engineering. In fact, no considerable embankment had to be made for that depth. An inlet canal was of necessity built from Dry Creek, which was its feeder, this in turn being supplied by two small canals in which a right of carriage had been purchased. The expenses of construction were increased from the fact that a wooden conduit was put in at first. The parties living under the reservoir deemed it unsafe. This necessitated its removal and the substitution of a cement and rock conduit, costing about $5,000. The quantity of land originally purchased was some 700 acres. This, with the right to run water through the inlet ditches, cost about one-fifth of the whole.

In 1895 the company resolved to increase the capacity to a depth of 30 feet. This required the construction of a bank over 2,000 feet long on the top, and this, with the additional land to be purchased, added to the cost $25,000 more, making the total cost about $90,000. This

VIEW OF HEAD GATES OF LARIMER AND WELD CANAL AND OF THE CANAL BELOW THEM.

addition of 5 feet to the upper surface increased the cubic contents by one-half. However, in being measured out over a weir, the reservoir does not come up to the estimated capacity by one-third. In fact, on drawing the water down from a depth of 29½ feet to 4 feet a content of only 325,000,000 cubic feet was given. This discrepancy between the capacity estimated from depth and contour, and measured as above is true of all other reservoirs in this valley that have been tested in the same way. The weirs are not constructed so that the Francis formula will apply to them, but they are rated by a current meter at different depths, just as the weirs in the canals are measured to find their intake from the river.

The accompanying views, Pls. IX, X, XI, illustrate the embankment and outlet of this reservoir. The first (Pl. IX) is a view from the inside of the reservoir after the water has been drawn off. The rectangular mass of masonry in the center is the wall of the well which surrounds the space where the gates are placed. Its interior dimensions are 6 feet by 10 feet. The wall is 3 feet thick and is composed of heavy rubble masonry laid in Portland cement and connected with flanking walls.

The next view (Pl. X) shows the lower side of the outlet of the reservoir. In the middle is the heavy lower retaining wall, extending only a portion of the way up the embankment. The latter was constructed of earth, with a slope of 1½ to 1. At the right are posts standing at various angles. These were driven into the ground to keep the earth from slipping into the canal below the masonry, as it was tending to do after becoming moistened by percolation from the water in the reservoir. The next view (Pl. XI) is at the lower end of the outlet canal of the reservoir where it discharges over the weir into the Larimer and Weld Canal.

On account of the exchanges which are being made for river water it will be apparent that a high degree of accuracy of measurement is desirable, or at least that the same system of measurement should obtain in measuring the outflow of the reservoirs and the intake of canals, and this is attempted; but those who have studied and experimented most on measuring water under ordinary and diverse conditions best know how difficult it is to obtain accurate results.

The large expenditure in litigation was brought about by the fact that after the reservoir had been constructed by the farmers the canal company refused to allow them to run the reservoir water in the canal. The farmers had contracts with the company to furnish them so much water, but they were not stockholders in the company. The contracts also provided that the holders of these contracts should become stockholders after the company had sold water rights to the estimated capacity of the canal to furnish water. But this limit, which was 500 eighty-acre water rights, had not been reached, and moreover these same farmers had gone into the courts asking an injunction

prohibiting the company from selling any more than the 370 rights that then had been sold, since there was a provision in the contracts that in times of scarcity the water was to be prorated with all the rights sold and in force. It was contended that the company had sold more than it could furnish, this word applying equally to the water to be obtained from the river and to the capacity of the canal to carry.

This case has been in court some five years. The company won in the district court and in the court of appeals, while these decisions were reversed in the State supreme court, which sent the case back for trial again in district court, which gave the farmers their case, as instructed by the upper court. However, there seemed to be another appeal to the supreme court, the company meantime being restrained from selling any more water rights until the case is finally adjudicated. The expenses of this case, as well as that concerning the reservoir's own suit, were paid by the reservoir company, and hence swells the account on this score.

As regards its own suit to compel the company to carry the water, an order to this effect was obtained from the county court of Weld County, which was, nearly as soon as given, countermanded by a judge of Arapahoe district court in the absence of the judge of this district; but upon hearing before this same judge, he reversed his own decision, and the farmers were allowed to carry their reservoir water in the canal of the company.

This was allowed partly on account of a statute of the State providing that a canal already in existence, and having the capacity and proper location to carry the water of a party not an owner of the canal, must carry it, and so prevent burdening the real estate with parallel canals, which were becoming a nuisance before the enactment of this law. In the present instance, if the farmers had been forced to build a canal to distribute their water, it must have been either immediately above or below a canal some 40 feet wide, and if above, they would have to flume across this canal wherever there was a lateral, the laterals being the property, in part at least, of the farmers who had lands under them. These laterals were as frequent as one a mile. On the other hand, if below, they would have to flume the reservoir's canal over each of these laterals, in fact, making a monstrosity of construction, a monument of human perversity and folly.

Of course, although the canal in an equitable sense belonged to each farmer in proportion to the quantity of water he had purchased to be delivered through it to his land, still legally the canal belonged to the canal company, and what the reservoir people got was a temporary easement for the use of the canal when there was but little or no water in the river to which the canal was entitled, and for this temporary use they were expected to pay. Another suit in court fixed the amount, which was made low by the jury, no doubt on account of *the virtual part* ownership of the farmers in the canal.

VIEW OF OUTLET AND EMBANKMENT OF LARIMER AND WELD RESERVOIR, FROM THE INSIDE. AFTER THE WATER IS DRAWN OFF.

They had paid, on an average, $1,000 apiece for each 80-acre water right, which was to be 1.44 cubic feet per second when there was water enough in the river. Taking out some 30 preferred rights granted the owners of the old ditch, there were in force some 340 of these rights, for which the company had received $340,000, while the construction of the canal had not cost more than $150,000. It was a part of the contracts with the farmers that they should become shareholders in the company as soon as the estimated capacity of the canal had been reached. But this question was in court, and, as we saw above, has been decided in favor of the farmers, namely, that it had been reached at the time they enjoined the company from further sales of water rights, because the deficiency of water in the river during the ordinary irrigation season prevented the company from being able to furnish. The ambiguous phrase "capacity to furnish" was at last, and by the highest court, construed against the company, which was the drawer of the instrument, in accordance with the general practice of the courts.

LAKE LEE.

At the time the order of the county court was issued to allow the reservoir people to take possession of the canal and run their water through to those entitled to receive it, there was running in the canal some 19 cubic feet of water per second belonging to its old appropriation. This was being stored in a reservoir named "Lake Lee," an expansion of the canal some 15 miles below its head. Its area is about 90 acres, and a depth of 9 feet can be drawn off when it is filled to the limit of height. When the water of the reservoir was turned into the canal, it mixed with that carried by the canal for the benefit of all consumers, while those owning and entitled to reservoir water were about one-half of the consumers. The order of the court therefore put the canal for certain-named days wholly in the hands of the reservoir people, under the penalty of damages to the other consumers. The writer was put in charge of the reservoir and canal at these times and until more amicable relations were restored. The plan adopted was to carefully measure the height of water in Lake Lee at the time the reservoir water reached it, and then to make an estimate as to the height to which the quantity in the canal would fill it during the days the reservoir water was being run. When the run was about finished, the outlet gates of Lake Lee were shut, so that there would be in it for all consumers what it was estimated would have been in it if the reservoir water had not been run. The instructions of the reservoir managers were to be sure and err on the side of leaving enough in Lake Lee, and the result was that no damages were claimed by the other consumers for loss of water by the operation of the canal by the reservoir company. Pl. XII shows the Larimer and Weld Canal at Lake Lee gates.

WINDSOR RESERVOIR.

It will be observed that this reservoir water was the property of about one-half of the consumers under the Larimer and Weld, and hence that only in the few cases where the others rented did they enjoy the use of the water. As a consequence, only those having reservoir water made a potato crop. Those outside of the reservoir, of whom the leader was B. H. Eaton, the owner of some 15,000 acres under the canal, undertook the construction of a reservoir for themselves. There is an excellent site for a reservoir some 25 miles from the head of the canal and close to it. The bottom of the canal at this point is about 50 feet above that of the reservoir. It has been filled to the depth of 28 feet and the water stored in it has been used for three years by means of the system of exchange before described. The cost of the reservoir up to date has been, as itemized by Mr. Eaton, as follows:

Land	$20,000
Condemnation and attorneys' fees	5,000
Outlet and inlet, the latter consisting mostly in enlarging the Larimer and Weld Canal from river to reservoir inlet	10,000
Surveying	1,000
Conduit and embankment	16,000
Total	52,000

The owners expect to expend $23,000 more to make it hold 12 feet more, or a depth of 40 feet of water at the conduit. This will be expended partly on the main canal, to enable it to take in flood water from the river for storage, and partly on the embankment. When the water is raised to the height of 40 feet, it is estimated the reservoir will hold 1,000,000,000 cubic feet.

The work on the embankment near the outlet conduit is in a very incomplete state, as will be seen from the accompanying view, Pl. XIII, taken from the inside of the reservoir when the water was drawn off. This shows the masonry in front and over the stone arch which forms the outlet. The gate, which is about 4 feet by 5 feet, is raised by a screw and lever. There is no flank masonry nor rock riprapping to protect the earth embankment. Such protective works were attempted by use of posts, poles, wire, and straw, but, as seen in the view, these were wrecked by the waves.

The conduit is of masonry laid in Portland cement; the bottom is of large, thick flagging stones procured in the foothills; the sides, 3 feet high and 4 apart, are crowned with an arch 2 feet high in the center; the walls of sides and arch, 2 feet thick, are of rubble masonry, resting upon the soft shale rock, which has between it and the flagging that forms the bottom some 6 inches of concrete made of gravel, sand, and Portland cement. There have been no signs of leakage along the surface of the conduit, but there is a tendency to

VIEW OF LOWER SIDE OF OUTLET OF THE LARIMER AND WELD RESERVOIR.

eak just above the shale into the outlet ditch below the end of the masonry of the conduit.

After the water has been raised in this and similar reservoirs the overlying clay becomes softened and sloughs off into the outlet canal. This was the occasion for great fear on the part of the people living under the Larimer and Weld Reservoir during 1895. A score or more of families abandoned their houses one rainy night when the reservoir was full and looked threatening. It is now proposed to wall up the outlet canals below the masonry conduits with a dry stone wall filled behind with gravel, which will allow the water to leak through while it prevents sloughing off.

When the Windsor Reservoir is complete it is planned to draw off the water at two levels, the one at the bottom, now in use, and another at a level 20 feet higher and distant 200 feet. The water from the upper outlet will be dropped into the same canal that is now used for the bottom level. The reason given for this is ease of management of the gates, which would be hard to raise under a pressure of 40 feet.

LARIMER COUNTY CANAL.

Larimer County Canal is to the north of and in general parallel with the Larimer and Weld Canal, covering a strip of land above the latter. It heads on Cache la Poudre Creek, about 8 miles higher up, but for its water supply this canal has for the most part been dependent upon a system of reservoirs, since it is the latest of those of large size in the valley, being preceded by 99 claims, aggregating 4,082.65 second-feet. In order of priority it follows third after the North Poudre Canal and Reservoir Company, there being two claims of 57.40 feet between. By its head in the main river, however, it obtains water whenever, at rare intervals, there is any.

This canal was built by residents of the valley, who, though having the evidence of a deficiency of water before them, yet hoped that the unusually large supply of previous years would prevail in the future. They overestimated not only the supply obtainable for storage in reservoirs, but also the land that could be sufficiently irrigated from a given amount of water. Hence it may be said that until the last two years farming under this canal has been a series of failures. This company has on the plains six reservoirs fed by the canal. Of these two are important, Long Pond and Rocky Ridge. These have a united capacity of 340,000,000 cubic feet, or 7,500 acre-feet. The total storage capacity of all its reservoirs claimed is 480,000,000 cubic feet, or 10,560 acre-feet.

CHAMBERS LAKE RESERVOIR.

A company known as the Larimer County Reservoir Company placed a dam in the outlet of Chambers Lake, a natural storage basin near the head waters of the Middle Fork of Cache la Poudre Creek. The

irrigators interested in the waters of this stream, fearing a scarcity of supply, commenced suit on the ground that the statute gave only the right to take water from a stream and store it, and not to place a storage dam in the stream itself. The dam, however, was constructed, but on June 9, 1891, it broke, letting the contents of the reservoir sweep down the channel of the river and inflicting much damage upon the farms situated in the narrow mountain valley. Passing through the canyon below the valley, it overspread the lower bottom lands, carrying away bridges, the force gradually diminishing as the mouth of the river was reached.

The parties injured sued and recovered damages, and as the reservoir company had no property but the destroyed dam, suits were brought against the Larimer Canal Company, on the ground that since it had been renting the water and was the controlling factor of the reservoir company it should be held responsible. It was held that any one placing a dam in a natural stream was responsible for injury resulting from its destruction.

The irrigators of the valley as a rule were not displeased to have this dam destroyed, as it was generally believed that water was unjustly taken from the river. The dam being 70 miles above the gaging station, out of the reach of the river commissioner, and wholly in charge of employees of the canal company, it was impossible to verify this belief. The experience gained here justifies the statement that no structure of this kind should be built except under State supervision or in accordance with regulations prescribed by the State engineer, such as will insure absolute safety in the building and management of dams, especially those upon the main drainage lines.

SKY LINE DITCH.

In 1892 the company owning the Larimer County canal was reorganized under the name "Water Supply and Storage Company," and during the next year undertook the work of building a ditch above Chambers Lake for the purpose of diverting into Cache la Poudre Valley water from the upper feeders of the Laramie River, a tributary of the North Platte. This ditch, shown in Pls. I and XIV, bears the graphic name of the "Sky Line," as it is about 10,000 feet in altitude. It is 5 miles long, has a capacity of about 100 second-feet, and cost $90,000. The work was practically all in rock, with but little flaming. In places it was necessary to build a bench of timber to support the lower bank, which is mostly of rock.

The Sky Line ditch takes water from streams so high up that it receives no supply until about the middle of June. The river commissioner estimates the amount delivered in 1895 at 650,000,000 cubic feet, or 14,300 acre-feet. During the season when water is being run the company keeps three men on this short canal to maintain it and *to regulate* the flow at the head so as to get as much water as possible.

VIEW OF OUTLET CANAL OF LARIMER AND WELD RESERVOIR, WHERE IT GOES OVER THE WEIR INTO THE LARIMER AND WELD CANAL.

As it is 70 miles above the gaging station, the river commissioner can not visit this canal to ascertain how much it is furnishing the river, and must depend upon the reports made by mail three times a week by the party in charge. When it has a full supply it furnishes about 00 feet, but later, by the 1st of September, it sinks to 25 feet. During 1894 and 1895 the water from the Sky Line ditch and that stored in the reservoirs has been practically all the supply the Larimer County Canal has had, and fair crops have been made. The capacity of the canal on the plains is said to be 469 feet, but it is apparent that it has only a sure supply of 100 feet besides the reservoirs, the contents of which are now used before the water from the Sky Line is available.

Since the reservoirs belonging to this canal are filled from it, the water, being at a lower elevation, can not run back and be distributed by means of it. Hence other distributing canals would need to be built and could supply water only to the lower lands. Instead of this, a system of exchange with the river has been adopted through the consent of all parties and in accordance with a ruling by the State engineer. This may be effected either by dropping the water of the reservoirs back into the river for the use of canals below, which are all older, or it may be accomplished by running the reservoir water directly into either the Larimer and Weld or the Cache la Poudre Canal when either is entitled to water. An equal amount is then claimed from the river. Not only do the reservoirs of this canal make this exchange, but also those filled from the Larimer and Weld Canal next below. This receives the river water of the Cache la Poudre Canal, which is just below and also older. This exchange has worked well and is a great saving of expense in construction of distributing canals. It also renders the water available for all the lands that the canal can reach.

The reservoirs of the Larimer County Canal Company have not been very expensive to construct, as but little or no embankments have been made. The conduits from the two principal ones are made of rock, the bottom and cover of large, thick flagstones, with joints filled with cement mortar, and the sides are of rubble masonry laid in cement. The largest two can be filled to 30 feet, and the gates are raised by a screw. Each cost for construction about $10,000 and $2,000 for right of site.

APPROPRIATIONS FROM CACHE LA POUDRE CREEK.

In addition to the three canal systems described above there are in all about 25 other canals and ditches taking water from Cache la Poudre Creek, most of these being relatively small. Without describing these it will be recognized that the apportionment of water among all these canals and ditches must be a matter of extreme difficulty. It is further complicated by the fact that many of these have more than one appropriation, so that although a list of the ditches as given

on pages 51–52 shows only 28, there have been up to 1888 as many as 104 separate appropriations of water from Cache la Poudre Creek and its tributaries, these being due to the amount of water claimed at the original construction and by the several enlargements, especially of the older ditches. The matter is fully set forth in the following table taken from the State Engineer's Report for 1888:[1]

Appropriations from Cache la Poudre Creek.

Order of priority in district.	Name of ditch, canal, or reservoir.	Date of appropriation.	Cubic feet of water per second decreed to each priority.	Summation of decree to each ditch, canal, or reservoir.	Cubic feet of water previously appropriated in district.
1	Yeager	June 1, 1860	24.80	.....	.....
2	Watrous, Whedbee & Secord	June 1, 1861	1.44	.....	24.80
3	Dry Creek	June 10, 1861	11.67	.....	26.24
4	Pleasant Valley and Lake	Sept. 1, 1861	10.97	.....	37.91
5	Pioneer	Mar. 1, 1862	12.92	.....	48.88
6	Boyd & Freeman	Mar. 15, 1862	66.05	.....	61.80
7	Whitney	Sept. 1, 1862	48.23	.....	127.85
8	Yeager (upper branch), first enlargement	June 1, 1863	8.70	33.50	176.08
9	B. H. Eaton	Apr. 1, 1864	29.10	.....	184.78
10	Larimer and Weld	June 1, 1864	3.00	.....	213.88
11	Pleasant Valley and Lake, first enlargement	June 10, 1864	29.63	40.60	216.88
12	Pioneer, first enlargement	Sept. 15, 1864	16.67	29.59	246.51
13	John G. Coy	Apr. 10, 1865	31.63	.....	263.18
14	John R. Brown	May 1, 1865	8.00	.....	294.81
15	Box Elder	Mar. 1, 1866	32.50	.....	302.81
16	Chamberlin	Apr. 1, 1866	14.83	.....	335.31
17	Taylor & Gill	Apr. 15, 1866	18.48	.....	350.14
18	B. H. Eaton, first enl	June 1, 1866	3.33	32.43	368.62
19	Watrous, Whedbee & Secord, first enlargement	July 1, 1866	4.33	5.77	371.95
20	Boyd & Freeman, first enl	July 15, 1866	9.00	75.05	376.28
21	Larimer and Weld, first enl	Apr. 1, 1867	16.67	19.67	385.28
22	Mason & Hottell mill race	Apr. 15, 1867	93.07	.....	401.95
23	Box Elder, first enl	May 25, 1867	8.33	40.83	495.02
24	Wm. R. Jones	Sept. 1, 1867	15.52	.....	503.35
25	Josh Ames	Oct. 1, 1867	35.92	.....	518.87
26	Martin Calloway *a*	Mar. 1, 1868	15.22	.....	554.79

[1] Fourth Biennial Report of the State Engineer of Colorado for the years 1887 and 1888, pp. 148, *149, 150.*

a Takes water from Boxelder Creek.

VIEW OF LARIMER AND WELD CANAL AT THE LAKE LEE GATES.

Appropriations from Cache la Poudre Creek—Continued.

ier pri-ity dis-ct.	Name of ditch, canal, or reservoir.	Date of appropriation.	Cubic feet of water per second decreed to each priority.	Summation of decree to each ditch, canal, or reservoir.	Cubic feet of water previously appropriated in district.
7	Noah and Philo Bristol (lower) *a*	Mar. 10, 1868	15.22	.....	570.01
8	Cañon Canal Co	Mar. 15, 1868	8.60	.....	585.23
9	Watrous, Whedbee & Secord, second enl	June 1, 1868	4.33	10.10	593.83
0	Box Elder, second enl	July 1, 1868	11.93	52.76	598.16
1	Irrigating Ditch Co	May 1, 1869	60.08	.....	610.09
2	Fort Collins	June 1, 1869	1.67	.....	672.17
3	New Mercer Ditch Co	Sept. 1, 1869	4.17	.....	673.84
4	Noah and Philo Bristol (upper) *a*	Mar. 1, 1870	14.83	.....	678.01
5	Canal No. 3, Union Colony	Apr. 1, 1870	52.00	.....	692.84
6	Dry Creek, first enl	Oct. 21, 1870	14.42	26.09	744.84
7	Cache la Poudre Co	Oct. 25, 1870	110.00	.....	759.26
8	Fort Collins Irrigating, first enlargement	Apr. 1, 1871	31.66	33.33	869.26
9	Burnham & Emerson *b*	do	26	.....	900.92
0	Wm. Calloway No. 1 *c*	May 1, 1871	21.05	.....	926.92
1	Mill Power	July 1, 1871	160	.....	947.97
2	Fletcher	Sept. 1, 1871	63.16	.....	1,107.97
3	Whitney, first enl	Sept. 10, 1871	12.95	61.18	1,171.13
4	Cache la Poudre Co., first enlargement	Sept. 15, 1871	170	280	1,184.08
5	Larimer and Weld, second enlargement	Sept. 20, 1871	75	94.67	1,354.08
6	Canal No. 3, first enl	Oct. 1, 1871	41	93	1,429.08
7	New Mercer Ditch Co., first enlargement	Oct. 10, 1871	8.33	12.50	1,470.08
8	Chaffee Irrigating	Mar. 15, 1872	22.38	.....	1,478.41
9	New Mercer Ditch Co., second enlargement	July 1, 1872	15	27.50	1,500.79
0	Canal No. 3, second enl	July 15, 1872	63.13	156.13	1,515.79
1	Pleasant Valley and Lake, second enlargement	July 19, 1872	16.50	57.10	1,578.92
2	Fort Collins Irrigating, second enlargement	July 20, 1872	33.33	66.66	1,595.42
3	B. H. Eaton, second enl	July 25, 1872	9.26	41.69	1,628.75

a Takes water from Boxelder Creek.
b Takes water from Lone Pine Creek.
c Takes water from north fork of Cache la Poudre Creek.

Appropriations from Cache la Poudre Creek—Continued.

Order of priority in district.	Name of ditch, canal, or reservoir.	Date of appropriation.	Cubic feet of water per second decreed to each priority.	Summation of decree to each ditch, canal, or reservoir.	Cubic feet of water previously appropriated in district.
54	Lake Canal	Nov. 1, 1872	158.35		1,638.01
55	Wm. S. Taylor	Mar. 15, 1873	28.60		1,796.36
56	Cañon Canal Co., first enl	Mar. 20, 1873	48.88	57.48	1,824.96
57	Larimer County Canal, No. 2	Apr. 1, 1873	175		1,873.84
58	Irrigating Ditch, first enl	May 1, 1873	20.42	82.50	2,048.84
59	Canal No. 3, third enl	May 15, 1873	16.65	172.80	2,069.26
60	Aquilla Morgan *a*	July 1, 1873	17.65		2,085.91
61	Brown No. 1 *b*	do	9.38		2,103.56
62	Boyd & Freeman, second enlargement	Aug. 1, 1873	24.23	99.28	2,112.94
63	Brown No. 2 *b*	Aug. 15, 1873	3.32		2,137.17
64	Strudevant No. 1 *c*	do	10.66		2,140.49
65	Strudevant No. 2 *c*	Aug. 20, 1873	10.66		2,151.15
66	Fort Collins Irrigating Ditch, third enl	Sept. 1, 1873	63.28	129.94	2,161.81
67	Dry Creek, second enl	Sept. 15, 1873	12.13	38.23	2,225.09
68	Vandewark	May 1, 1874	10.17		2,237.22
69	Brown No. 3 *b*	May 15, 1874	3.32		2,247.39
70	Mitchell & Weymouth No. 1 *d*	do	17.35		2,250.71
71	Andrew Boyd et al. *b*	Nov. 1, 1874	15.03		2,268.06
72	Cache la Poudre Co. Canal, second enlargement	Nov. 10, 1874	184	464	2,283.09
73	Larimer & Weld, third enlargement	Jan. 15, 1875	54.33	149	2,467.09
74	Wm. Calloway No. 2 *a*	Jan. 28, 1875	14.16		2,521.42
75	Witzler et al. *d*	Mar. 22, 1875	10.36		2,535.58
76	Warren Lake Reservoir (see. 56)	Apr. 15, 1875			
77	Brown, No. 4 *a*	May 1, 1875	6.72		2,545.94
78	Kitchel & Ladd	Oct. 1, 1875	2.95		2,552.66
79	Brown, No. 5 *a*	June 1, 1876	6.72		2,555.61
80	Brown, No. 6 *a*	do	6.72		2,562.33
81	Witzler et al., first enl. *d*	Mar. 1, 1877	3	13.36	2,569.05
82	Brown, No. 7 *a*	June 1, 1877	2.85		2,572.05

a Takes water from north fork of Cache la Poudre Creek.
b Takes water from Fish Creek.
c Takes water from Boxelder Creek.
d Takes water fro mLone Pine Creek.

VIEW OF OUTLET OF WINDSOR RESERVOIR FROM THE INSIDE.

Appropriations from Cache la Poudre Creek—Continued.

ler ori- ty dis- ct.	Name of ditch, canal, or reservoir.	Date of appropriation.	Cubic feet of water per second decreed to each priority.	Summation of decree to each ditch, canal, or reservoir.	Cubic feet of water previously appropriated in district.
3	Cache la Poudre Co.'s, third enlargement	Sept. 15, 1877	121	585	2,574.90
4	Henry Smith	Apr. 1, 1878	7.23		2,695.90
5	Abram Washburn, No. 1	Apr. 15, 1878	9.57		2,703.13
6	Roberts, No. 1 *a*	do	5.76		2,712.70
7	Boxelder Reservoir Co. *b*	June 18, 1878	17.50		2,718.37
8	Larimer and Weld, fourth enlargement	Sept. —, 1878	571	720	2,735.87
9	Carter Cotton mill race	Apr. 1, 1879	127.30		3,306.87
10	Abram Washburn, No. 2	Apr. 15, 1879	15.43		3,434.17
11	Dry Creek, third enl	July 15, 1879	12.70	50.92	3,449.60
12	Pleasant Valley and Lake, third enlargement	Aug. 18, 1879	80.83	137.93	3,462.30
13	John McKay et al. *a*	Sept. 1, 1879	3.40		3,543.13
14	Fisk, No. 2 *a*	Dec. 1, 1879	10.28		3,546.53
15	Carter Cotton mill race, first enlargement	Dec. 31, 1879	37.17	164.47	3,556.81
16	Mitchell & Weymouth, No. 2 *c*	Jan. 19, 1880	16.27		3,593.98
17	North Poudre Land, Canal and Res. Co. *a*	Feb. 1, 1880	315		3,610.25
18	New Mercer Ditch Co., third enlargement	Feb. 15, 1880	136	163.50	3,925.25
19	Chase *a*	July 7, 1880	21.40		4,061.25
20	Larimer County	Apr. 25, 1881	469.80		4,082.65
21	Eagle Ranch *a*	Oct. 1, 1881	5.02		4,552.45
22	Pleasant Valley and Lake, fourth enlargement	Oct. 10, 1881			
23	Emerson Bros. *c*	Apr. 15, 1882	29.88		4,602.65
24	Roberts, No. 1, first enl *a*	Sept. 1, 1882	*d*4.09		4,632.53

Takes water from north fork of Cache la Poudre Creek.
Takes water from Boxelder Creek.
Takes water from Lone Pine Creek.
Up to 1897 only two changes have been made in this table. The first is in the reduction of 1, Yeager Ditch, from 24.80 cubic feet per second to 3 cubic feet per second. The second is a nge in the order of priorities, by which No. 100, Larimer County Canal, becomes 97 and old 8, and 99, become, respectively, 98, 99, and 100.

The above table is worthy of especial notice, since it is the guide r the district water commissioner in his distribution of water. hen an earlier appropriator of water has less at his head gate than

he needs, and when he believes that some later appropriator farther up the stream is getting water to which he deems himself entitled, he notifies the water commissioner, usually by telephone, of the situation, and if the commissioner deems his complaint well grounded, No. 104 is shut off, then 103, and so on up the list until the deficiency is remedied.

It will be seen that some of the canals have several enlargements, each of which stands upon its date of construction, as decreed by the district court. Cache la Poudre Company's Canal—original name, No. 2, of Union Colony—is an example. The original construction, No. 37, dates back to October 25, 1870. It is credited with a capacity of 110 second-feet, but there were 36 claims on the river preceding it, demanding in the aggregate 759.26 second-feet. The first enlargement, No. 44, dates from September 15, 1871, and is credited with 170 second-feet, which at that date made its total capacity 280 second-feet. At that time 43 claims preceded it, with an allowance of 1,184.08 second-feet. The second enlargement, No. 72, dates from November 10, 1874, and is credited with 184 second-feet, making in all 464 second-feet. This enlargement is preceded by claims for 2,283.09 second-feet. The third enlargement, No. 83, dates from September 15, 1877, and calls for 121 second-feet, making in all 585 second-feet, being preceded by claims for 2,574.90 second-feet.

The capacity of the river is such that if all these claims were valid there would be scarcely enough water to allow this canal its last appropriation, much less the Larimer and Weld for its fourth enlargement, No. 88, or 571 second-feet, its principal appropriation, but which is preceded by claims for 2,735.87 second-feet, which exceeds even the average June supply for every year on record excepting 1883, 1884, and 1885.

The third irrigating system in point of size is the Larimer County Canal. It is appropriation No. 100, and the canals preceding it call for 4,082.65 second-feet, a volume to which the river rarely ever rises, and which has been exceeded only in June 1883 and 1884.

To illustrate how excessive is the rating of these older ditches, take the Boyd and Freeman Ditch. It stands No. 6 on its original construction, and is granted 66.05 second-feet, dating March 15, 1862, or eight years before the settlement of Union Colony at Greeley. By reference to the table it may be seen that this ditch claims only 900 acres under it, mostly grass. This would give a duty of only 13.7 acres per cubic foot per second, even if it claimed only its first appropriation. In addition to this, however, it has two enlargements, bringing its claims up to 99.28 second-feet, or a duty of only 9 acres per second-foot. This matter is further discussed at length in the reports of the State engineer, notably in the Sixth Biennial Report, for 1891 and 1892, pages 13 to 17.

EXTRAVAGANT CLAIMS TO WATER.

This excessive adjudication was obtained largely by false testimony or was due to the ignorance of the witnesses, not even those who pretended to be engineers being able to compute the probable capacity of a canal from its slope and sectional area. Where formulas were used they were not applicable to small, crooked, poorly constructed ditches, such as were the early ones. Had there been water running in the river at the time the referee of the court took the testimony, the actual size of the ditches could have been approximated somewhat more closely; but it was late in the autumn of 1879 when this was being done, and the river was very low at the time. Moreover, there was no attempt made by the referee to have the ditches measured. This could have been done in the case of the smaller ones, which were also the ones whose capacity were the most excessively estimated. How much the capacity of the canals exceeds the supply can be seen by comparing the above decreed allowance with the table of estimated mean monthly flow given on page 27.

CACHE LA POUDRE CREEK.

When, in 1870, the Union Colony settled in the lower end of the valley and founded the town of Greeley, there were only about 1,000 acres in cultivation, all upon the bottom lands near the river, but the small canals then constructed claimed and had awarded them as appropriated 692.84 second-feet. There were in all some 23 small ditches taken out of Cache la Poudre Creek before 1870. If from this number are taken 4 small canals that were afterwards enlarged and at this time claimed only 42 second-feet, it is found that the 19 remaining ditches had under them in crops, according to the report of the State engineer for 1888, only 5,660 acres. To water this area they had at this latter date claims awarded them to the amount of 650 second-feet, or a cubic foot for every 10 acres. However, a provision in each decree restrains each ditch to so much of the quantity awarded as is needed for beneficial use and prohibits all waste. There are only 9 canals shown in the State engineer's report for 1894 that have records of the water taken in at their head gates for that year. These had crops to the extent of 106,000 acres, while the remaining 19 had only about 10,000 acres under crops. The fact is that by means of the irrigation of the uplands under the later larger canals, the lands under these lower canals, for the most part, need no water, but are, on the contrary, in many instances transformed into swamps.

There has been an opinion prevalent among the owners of the bottom-land canals that they, in some way, owned the water awarded by the court to their ditches which they could sell to other ditches when they did not need to use it where originally located. Moreover, if they did not need all of the water, or if, in fact, their ditches

could not carry it, the owners thought that they had a right to sell or transfer the remainder to such persons or places as they might find convenient. While there might be some justice in allowing a person whose land was ruined by the irrigation of the uplands a right to use as much water as he had actually used upon these lands through some other canal, it would have been ruinous to later canals to allow a transfer of the excessive quantities erroneously decreed to the earlier. This situation is now well understood, and later decrees by the courts in other districts base grants to water to a canal only to the extent that it is proved that the water has been applied. These excessive claims allowed by the courts affect every district in the division of the Platte, and are even more extravagant in others than in Cache la Poudre district; so the people of Greeley engaged an attorney to cross-question witnesses and restrict claims as much as possible.

CONSERVATION OF WATER SUPPLY.

From a consideration of the appropriations of water from Cache la Poudre and a comparison of these with the amount actually flowing at the upper end of the valley, it is evident that there must be a deficiency in ordinary years. In years of scarcity the lands under all but the oldest canals do not have sufficient water to enable them to make a full crop. This is demonstrated by the fact that in 1894 the crops under all the later canals were more than double those of the averages of the preceding five years, these being periods of less than average flow. Even in 1894 the lands under the older canals, having all the water needed, produced better than those more stinted. This is shown by a comparison of the lands under the three largest canals of the valley. These are shown in the following table in the order of priority of appropriations:

Name.	Total area in crop.	Quantity of water.	Depth.
	Acres.	*Acre-feet.*	*Feet.*
Cache la Poudre Irrigation Company's canal	22,045	70,610	3.2
Larimer and Weld Canal	44,384	77,225	1.7
Larimer County Ditch	16,714	27,830	1.66

It is shown that the acreage under the first is about half that under the second, and, as can be seen from the table on page 52, there was half as much wheat, about as much oats, more than half as much barley and corn, and more potatoes. The latter is the most important crop, one-fourth of the land cultivated under each of these two canals being in potatoes. The showing under the Larimer County Ditch was still worse, as it had more than two-thirds as much land as the first

under crops, while it had less than two-thirds as much wheat, less than one-third as much oats, a trifle more than its ratio of barley, but less than one-fifth as many potatoes.

These three canals, it will be seen, have under them about two-thirds of all the land in the valley. The rated capacities of these canals, for which the court has issued decrees, are 580, 720, and 480, the sum being 1,780 cubic feet per second. The total claimed by canals in this district at the end of 1888 and for which decrees had been granted them by the court, as shown on page 47, was 4,632.53 second-feet; that is, three canals have set apart to them by appropriation, as the decrees of the court stand, only about 38.4 per cent of the flow of the stream, while they have 66.6 per cent of the land irrigated. Many of the smaller ditches never could carry the quantities which were granted them by decree of the district court, and if they could carry them, they could not possibly use them.

CROP AREA.

The following table gives the crop statistics of Cache la Poudre Valley as obtained from a house-to-house canvass of the entire district.[1] Although absolute accuracy is not attainable in such matters, it is more nearly complete than anything of the kind that has been heretofore attempted in this State. There is also appended in the right-hand column a statement of the water received in 1894 by the nine principal canals, these being the only ones concerning whose intake a record was kept by the district commissioner:

Crop statistics in district No. 3—1894.

Name of canal or ditch.	Total.	Alfalfa.	Other grass.	Other crops.	Pasture and waste.	Wheat.	Oats.	Barley.	Corn.	Potatoes.	Fruit.	Water used.
	Acres.	*Acres*	*Acres*	*Acres*	*Acres*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Sacks.*	*Acres*	*Acreft.*
North Poudre	11,149	843	795	2,430	7,081	41,731	20,102	1,793	3,775	5,087	3	18,306
Larimer County	27,844	4,010	.....	12,847	11,131	89,774	23,855	7,209	4,075	113,795	35½	27,803
Larimer and Weld	59,507	7,428	878	32,182	15,123	283,998	80,004	17,599	6,702	554,303	53½	77,225
Pleasant Valley and Lake	8,221	1,750	470	2,234	3,110	7,338	11,578	830	1,972	3,655	123	17,387
New Mercer	4,256	1,664	174	1,020	1,867	17,990	21,941	8,075	2,032	13,448	101½	11,110
Larimer County, No. 2	8,623	2,751	61	2,640	985	34,881	14,190	7,120	280	10,389	70½	18,545
Fort Collins	1,179	492	45	387	374	720	799	425	65	860	33	.....
Dry Creek	3,160	1,131	223	453	991	1,989	3,257	.....	.....	350	41½	7,984
Little Cache la Poudre	1,300	567	61	642	204	1,544	2,033	.....	.....	1,420	24½	.....
Taylor & Gill	464	159	9	174	164	.....	300	175	100	1,350	28½	.....
John R. Brown	290	60	75	70	85	.....	490	.....	.....	.....	5	.....
From seepage	.....	62	115	433	450	2,700	6,245	2,435	1,530	8,050	4	.....
Cañon	497	160	5	90	197	250	120	57	300	500	5	.....

[1] Seventh Biennial Report of the State Engineer of Colorado, for the years 1893 and 1894, p. 22.

Crop statistics in district No. 3—1894—Continued.

Name of canal or ditch.	Total.	Alfalfa.	Other grass.	Other crops.	Pasture and waste.	Wheat.	Oats.	Barley.	Corn.	Potatoes.	Fruit.	Water used.
Watrous, Wheedbe & Secord	*Acres.* 120	*Acres* 20	*Acres*	*Acres* 25	*Acres* 75	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Sacks.* 600	*Acres*	*Acre-ft.* .....
Box Elder and Res. Co.'s	1,280	50	.....	100	1,000	900	300	.....	25	200	.....	.....
Josh Ames	460	24	50	110	276	1,600	516	1,100	150	1,400	.....	.....
City	26	3	.....	3	20	.....	.....	.....	.....	.....	.....	.....
Lake	6,242	1,007	156	1,762	2,076	19,900	15,516	1,282	3,855	23,280	10½	11.32
John G. Coy	300	60	80	45	115	260	240	.....	75	620	.....	.....
Pioneer	682	260	50	55	442	240	1,700	.....	.....	1,000	2	.....
Box Elder	1,735	270	144	351	1,028	1,077	1,467	634	95	3,184	.....	.....
Cache la Poudre Irr. Co.'s	33,173	5,032	704	15,065	11,128	144,224	82,628	9,837	3,670	602,485	42½	70.610
Whitney	2,080	358	55	652	683	4,410	6,051	.....	100	17,500	3½	.....
B. H. Eaton	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Cache la Poudre Irr. Co.'s, No. 3	1,275	147	103	517	480	1,875	1,140	.....	.....	14,652	.....	.....
Wm. R. Jones	360	75	119	135	149	300	1,600	.....	250	2,240	1	.....
Boyd & Freeman	900	90	350	300	158	.....	1,575	1,575	300	7,000	2	.....
Ogilvy	3,800	720	.....	1,357	1,728	13,200	7,465	.....	.....	29,660	.....	.....
Total	178,923	29,193	4,722	76,119	61,120	671,000	314,112	60,146	29,351	1,417,628	591½	290.28

From the above table it will be noted that there are 61,120 acres recorded as waste and pasture land. Parts of this, perhaps not more than 2,000 acres, are above the levels of the canals, but the larger proportion is near the river and is kept so wet by the irrigation of the uplands that it needs no further application of water. Much of it has changed into cat-tail and rush-bearing swamps. This is true of certain basins and valleys among the uplands. Some of these basins have been utilized as reservoir sites. These are chiefly found in the upper end of the valley, on the north side. The surface of the country here is quite rolling. The soil is a somewhat stiff clay, resting upon a soft argillaceous shale which rises to near the brim of these basins, and thus renders them nearly water-tight.

Nearly all the land under cultivation, that is, under canals, is on the north side of the river, the only exception being a small area of about 12,000 acres near Fort Collins. The reason is that below the point where the canals on the south side are seen to terminate the level of the land rises abruptly from the first bottom of the river to a height of from 50 to 100 feet. Near Greeley the bluffs lower and enable a small area in and near the town to be brought under a canal taken from Cache la Poudre Creek about 6 miles above the place. The hilly region to the south and west of Greeley is irrigated by the Loveland and Greeley Canal, which takes its water from Big Thompson Creek, *the next* tributary of the Platte above Cache la Poudre Creek.

AMOUNT OF WATER USED.

The mountain watershed of Cache la Poudre Creek above the gaging station is about 1,060 square miles, or 678,400 acres. The area actually irrigated by the water which passes this point was computed by Prof. L. G. Carpenter to be 135,000 acres,[1] this being less than one-fourth of the extent of the mountain gathering ground. The total discharge as measured by the intake of the canals in 1894 during the irrigating season is computed by Professor Carpenter at 284,000 acre-feet. This would give a depth of run-off for that period of about four-tenths of a foot for the mountain watershed. This was a year of far more than average flow. It has been stated that the average for the four years ending 1892 was 227,302 acre-feet, which would give a depth of yearly run-off of about one-third of a foot.

The average discharge of all of the tributaries of South Platte River for the five winter months—November to March, inclusive—for four years, as given by the reports of the State engineer, was 472 second-feet, or 141,364 acre-feet. As irrigation is carried on during the other seven months, this amount is all that was available for storage except during times of flood.

The discharge of Cache la Poudre Creek for the five winter months was, from an average of these four years, 24,858 acre-feet, a quantity much exceeded by the capacity of reservoirs now constructed. The total average flow of the tributaries of Platte River for the other seven months is approximately 1,900 cubic feet per second, which for 213 days would be 34,966,000,000 cubic feet, or 769,252 acre-feet. The average for Cache la Poudre Creek for same months of the four years is about 500 cubic feet per second, or 9,202,000,000 cubic feet, or 202,444 acre-feet.

The area irrigated in 1892, as given in the engineer's report for the Platte division, was 678,620 acres, while in Cache la Poudre district it was 162,239 acres for the same year. This would give a depth of 1.13 feet over the area of the division of the Platte and of 1.24 feet for the Cache la Poudre district from the water received through the canyons of the respective streams. To this must be added the amount received from return seepage, or "underflow," which is used within the Platte division. The greater portion of the return from irrigation of Cache la Poudre district is also used within that district. As nearly as can be estimated, the return at that time was, for the whole division, about 1,000 second-feet, while that used in Cache la Poudre district is about 100 second-feet. This, added to the depths, respectively, would give for the division a depth of 1.70 feet of water applied, and for the Cache la Poudre district 1.49 feet.

The water flow during the four years under consideration, namely, 1889–1892, was below the average. The amount of water taken into

[1] Colorado Experiment Station Bulletin No. 22, January, 1893, p. 24.

all the canals during the irrigation season of 1894 in Cache la Poudre district, as measured by the commissioner of the district, was 260,232 acre-feet. If the same number of acres are considered as irrigated as in the other period, these results for 1894 give a depth of 1.70 feet. If, however, the area stated to be under crops in the report of the commissioner is taken, including in this meadows and alfalfa fields and rejecting that included under the heading "Waste and pasture lands," which are scarcely at all irrigated, it is found that the water received by the canals would have covered the land to the depth of 2.45 feet. This leaves out of account the waste by evaporation and percolation from some 332 miles of main canals and several times that length of laterals, which would be not less than 20 per cent. This amount, subtracted from the above, gives a depth of 1.96 feet.

QUANTITY AVAILABLE FOR STORAGE.

It has been found that the average flow through the canyon for the five months from November to March is about 84 second-feet. If to this is added the return underflow between the gaging station at the canyon and the head of the canal that feeds Cache la Poudre reservoir, there will be had the total winter water available for storage.

The shrinkage in return underflow during the winter, when the lands draining into the Poudre are not being irrigated, is greater in the upper end of the valley, between Fort Collins and the gaging station, than between Fort Collins and the mouth of Cache la Poudre Creek on account of the narrowness of the upper irrigated belt compared with the lower. In other words, the return underflow will be more constant in proportion to the width of the belt irrigated, since lands adjacent to the stream soon drain back into it all their surplus water when the source of this is cut off.

The average gain from the canyon down to Fort Collins, as shown by the two autumn seepage measurements of 1893 and 1894, was 28 second-feet, and by that of March, 1894, was 5 second-feet. The mean of these gives a little over 16 second-feet, which can be added to the winter flow through the canyon of 84 second-feet.[1] This gives an average total for storage purposes of 100 feet. All the underflow below this, out of the irrigation season, goes into the Platte and is not now stored, nor can it be stored for use on the lands of Cache la Poudre Valley. Suitable basins are found below on the north side of the Platte, in which can be stored the winter waste of the Platte and all its tributaries. These basins have been surveyed and articles of incorporation filed for their construction, but the enterprise is supposed to involve the expenditure of a million and a half dollars, and the capital to push it through is not yet forthcoming.

[1] Colorado Agricultural Experimental Station Bulletin No. 33. Seepage or return waters from *irrigation*, by L. G. Carpenter, pp. 20-22. Jan., 1896.

The total average winter supply of Cache la Poudre Creek for storage in reservoirs, all of which are now adjuncts of the four largest canals, may therefore be set down at 100 feet per second for 150 days, 1,296,000,000 cubic feet, or 29,750 acre-feet. Those under the North Fork canal do not come under this estimation, as the water they have been storing comes from that tributary above the gaging station.

The reservoirs of the Larimer County Canal claim 458,000,000 cubic feet, the two largest ones of the Larimer and Weld 900,000,000, and the Cache la Poudre Reservoir claims 368,000,000, making in all 1,726,000,000 cubic feet, and if this be reduced 30 per cent for overestimation, we have a corrected capacity of 1,208,000,000 cubic feet, or 88,000,000 cubic feet less than the average available winter supply. But this does not take into account evaporation and percolation that are taking place the year round from the reservoirs. The five main reservoirs have an average water surface for the year of about 1,200 acres, the minimum being about 300 acres and the maximum 2,100. The evaporation from a water surface in this climate is found to be about 6 feet deep. This would give a loss from the surface of the reservoirs of 7,200 acre-feet, or 313,000,000 cubic feet.

The extent of percolation can be estimated with much less certainty; but from the character of the sites of all the storage basins, save that of the Cache la Poudre Reservoir, it can not be great, since they are underlain by an impervious shale rock which also rises to form their rims. A tenacious clay overlies this rock, and hence it would appear that percolation would be small except through the artificial embankment, where it may be large; but that part of the escaping water which gets into the channel of the outlet canal is inconsiderable. If the percolation from these reservoir sites, estimated at 2,000 acres, was equal to that through the surface of the irrigated land of the valley, it would amount to 2 feet per second, or to 63,000,000 cubic feet for the year. It is quite likely that it is as much as this owing to the great pressure during that part of the year in which the reservoirs are well filled, and the average for each reservoir would be only two-fifths foot per second. This would make a total waste of 376,000,000 cubic feet, which is 288,000,000 cubic feet more than the river's estimated surplus. From the above estimates it is apparent that the average winter flow that can be utilized by the large reservoirs is inadequate to their needs. Besides this, it is not desirable, as a rule, to completely fill the reservoirs before the storms set in, as the spring winds drive heavy waves against the lower embankments, they being situated in the direction opposed to the prevailing northwest storms.

RESERVOIRS.

Besides the reservoirs mentioned there are a number of small ones, especially under the Larimer and Weld and the Cache la Poudre canals. Under the former the claimed storage capacity is about 175,000,000 cubic feet, and under the latter about 110,000,000 cubic feet. These reservoirs are used by one or more parties for storing the water from the canals when it is not needed, and to catch as much as possible when water is plenty. They have no independent means of drawing directly from the rivers. A number of reservoirs are in use, and more are projected that will obtain their supply from seepage water. One very large concern, the corporate name of which is the Windsor Reservoir and Canal Company, proposes to store 510,000,000 cubic feet in two reservoirs filled entirely from a ditch cut through a swamp made by irrigation.

Nearly all the reservoirs are connected with the four principal canals of the north side and are on the upper end of the canals. It happens that there is a series of depressions or basins naturally suited for this purpose in that part of the valley where they can be of most use. Farther east the land slopes gradually to the southeast or in the general direction of the dry creeks outlined on the map (fig. 2). In this lower end of the irrigated area the soil, though deep, is underlain by a heavy body of gravel, which gives good drainage and prevents water-logging. Such a formation would be very undesirable under a reservoir, since, if not puddled, it would allow the water to waste by percolation.

In the reservoir region the soil, which is a stiff clay, lies directly on argillaceous shale. About 7 miles north of the river, near the lower end of the valley and on the ridges between the valleys of the dry creeks, the Laramie coal-bearing formation is found, and it extends thence northwest of Eaton, at which place alone it is mined. The depth to the coal is about 75 feet through clay, for the most part, the coal having a shale roof. The formation is dry here, but to the west is wet by the extensive irrigation practiced above.

The basins which have been utilized as reservoirs appear to have been formed by flexures or faults in the strata, and not by erosion, since in cutting the outlets the rock is found in the lower edge of the rim higher than it is toward the center of the basin. This rock is practically impervious to water. When the rock is wet, the water takes a lateral course over its upper layer, the clay next to it becoming quite soft and even disposed to slough off where a cut is made. This is the weak place in the structure of reservoirs on these sites, and has caused alarm on the part of people living under them.

There are now more reservoirs in the valley than can be filled with the available water. As a consequence the owners are asking that laws be passed fixing more definitely the time of year when water may *be stored in* preference to being used for irrigation. The regulations

now require that water companies keep their canals running for the use of consumers from April 1 to November 1, except during the time taken for necessary cleaning and repairs. The reservoir law provides that any person shall have the right to take from natural streams of the State and store away unappropriated water not needed for immediate use, for domestic use, or for irrigating purposes. The general theory is that when growing crops need water for irrigation the person having such crops has a right to it superior to those wishing to store it for future use, even though the works constructed for storage purposes antedate the canal supplying such growing crops.

The superior rights for immediate irrigation is supposed to exist especially during the seven months that canals are required to be kept running, even though the water is being used only for moistening the soil for the mechanical purpose of enabling it to be more easily plowed or for storing up moisture for next year's use. The owners of a canal that has no reservoir constructed on purpose to store water for its use in times when it is not needed for irrigation may well claim that the soil on their farms answers such a purpose, and that they have as good a right to run water onto these farms whenever they can as the owners of canals with reservoirs have to run it into the latter. These parties insist that the only time when they can be prohibited from using water is the one in which nature withholds it from them, namely, when it freezes so hard that they can not run it onto the land. This time differs so much in different localities of the State and is also so dependent on the character and situation of the works of diversion that it precludes any rules being laid down by the legislature.

If the canals now having reservoirs were without them, they would have a prior claim for use of the water after the crops were grown (provided they had a prior right for the irrigation of growing crops), and the fact that they have built reservoirs to store the water at times when it is not needed for growing crops should not, in the judgment of the writer, impair their rights to store the water instead of using it on the soil which is to play in part the purpose of a reservoir.

If such were the rule, every canal's right to water for storage for future use would have the same date as the rights of the canals of which they are adjuncts. The rule, however, is that reservoirs have prior rights to water for storage among themselves according to date of filing claims with the State engineer, provided the work be prosecuted with due diligence, irrespective of the claims of the canals to which they are adjuncts.

All the reservoirs in the Poudre Valley are adjuncts of some canal previously built, and are constructed to furnish such canals at times of scarcity in the river during the season that growing crops need irrigation. This is usually in the latter part of the season and for the potato crop, which is grown extensively, especially in the lower end of the valley. The quantity of water available for this purpose is, as

above stated, now exceeded by the capacities of the reservoirs, and parties are in court disputing one another's claims. It appears more likely that the courts will work out some generally recognized rule than that the legislature will be able to pass any law of general application, since the different irrigation localities hold diverse views and, indeed, have diverse conditions to be satisfied.

NORTH POUDRE LAND, CANAL, AND RESERVOIR COMPANY.

The North Poudre or uppermost of the canals, though among the latest in construction—its appropriation being No. 97 in the district—was the first to avail itself of reservoirs. The necessity for storing water which could not be used in the irrigation season early pressed itself upon the attention of the proprietors, not only because this canal was among the latest to appropriate water, but because the North Fork, from which it takes its supply, does not head back so far in the Snowy Range as do the other branches of the Poudre, and hence its water supply fails or becomes low early in the irrigation season. With perhaps the exception of the Larimer County Canal, these reservoirs are of more vital importance than those of any other canal in the district.

The number of reservoirs recorded in the reports of the State engineer up to 1894 is four. The date of the filing of these is December, 1891, but it is claimed that work was begun in 1883, and contention is made that priority dates from the commencement of work rather than from the date of filing claim, provided the work has been prosecuted with due diligence and the water applied to beneficial use within a reasonable time. This question is still in the courts, but reasoning from the position taken in regard to canals, it may be inferred that the contention will be sustained. Without these reservoirs the canal would be worthless.

The quantity claimed for these four reservoirs is 330,000,000 cubic feet, or 7,260 acre-feet. The proprietors of the canal report, in all, 12 reservoirs, with a united capacity of 800,000,000 cubic feet, or 17,600 acre-feet; but these later claims come after those of other important reservoirs, which may exhaust the supply available for storage.

A dam of considerable elevation was required at the point of diversion from the stream to raise the water into the head of the canal. This structure was made of timbers and loose rock, both obtained close by, and has proved so far safe and durable, in spite of the fact that the engineer, Patrick O'Meara, had but little faith in so loose a structure, built in part of perishable material. At its head the canal has also about a mile of fluming, a large portion of which rests on the rock prepared for it along the edge of the mountain. This flume has recently been replaced, and has needed much repairing. The dam *and upper part* of the flume are shown in the accompanying view *(Pl. XV)*.

VIEW OF DIVERSION DAM OF NORTH POUDRE CANAL.

In proportion to its capacity, this canal is the most expensive in ıe district, having some tunneling besides the fluming. The cost is ıid to have been $150,000, which probably includes some work on ıe reservoirs. This latter was mostly done by the "Hartford Trust ıd Loan Company," behind which stands the "Travellers' Insurance ompany." This company furnished most of the funds, and soon ıme in possession of the work and the land under it, which is said) be 16,000 acres. The company has found it a most expensive ıvestment. It is stated that for the twelve years the net expendiıre over income has been at least $10,000 per annum, this including ıe work done on the reservoirs. The flumes rebuilt under the direcon of Engineer J. C. Ulrich are said to be models in this line of ɔnstruction. One of these[1] is 2,200 feet long and 25 feet wide at ıe upper end, gradually tapering to 15 feet at the place where the ater acquires its maximum velocity. The side planks are bolted, ıstead of being nailed to posts, and at the lower end the flume is

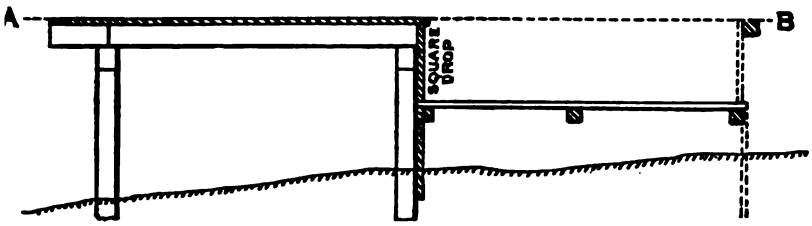


FIG. 7.—Vertical section of drop on North Poudre Canal. A B, line of canal.

iven a perpendicular drop to guard against moving out, a tendency ı flumes ending on the level with the canal below them. This endıg of the flume is illustrated by fig. 7. In the new flumes all the ımber used is well seasoned and tarred, and this, in the opinion of ıe engineer, will much increase its durability.

The outlets of the reservoirs are deemed among the best in the tate. They consist of iron pipes laid in Portland cement masonry ıd closed at the lower end by means of waterworks valves. In the ırger reservoirs two pipes instead of one are used, to secure the easier ɔeration of the valves. The fact that the means of opening and disıarging the reservoir are at the lower end of the conduit pipes, and ɜnce not covered by the water of the reservoir, as they are when ther at the upper end or in the middle, is a great convenience and ıards against numerous difficulties that attend operating under ater. In the case of the North Fork Canal reservoir system a small ischarge from each of its reservoirs into the canal will compensate ır want of ample discharge in each separately.

[1] Annual Report of Am. Society of Irrigation Engineers, 1893, p. 186.

EXCHANGES OF WATER.

Besides the cases above mentioned, other friendly exchanges are made by the canals and reservoirs of different companies. During the season of 1895, Cache la Poudre Canal began to receive from the river widely fluctuating amounts, the quantity carried being on one day as high as 200 second-feet and on the next 25 second-feet. It is exceedingly difficult to distribute such a supply fairly to the consumers. In this emergency, the proprietor of the Windsor reservoir, just above the canal, allowed the water to flow through the Larimer and Weld Canal into his reservoir, and then to be drawn off in definite quantities for a definite time.

These civilities are the more worthy of notice, since all three of the parties have been and still are engaged in litigation as to their respective rights to storage water. Three suits have already gone through the district court and are now before the supreme court of this State. The claims of reservoirs to water for storage have never been subjected to a general judicial inquiry, like that given to claims of canals.

The law provides that when any party proposes to construct a reservoir he must send a notice, supported by affidavits, setting forth the name of the reservoir, the source of its supply, the name of its feeder, the time of commencing work on it, and its capacity in cubic feet. The data thus furnished is for the guidance of the river commissioner in allowing reservoirs to have water for storage, but may be attacked in court and claims there made good. In these investigations the time of commencing work gives precedence, provided work is prosecuted with due diligence, but the whole quantity that the reservoir can hold may not be granted as of date with the commencement of the work, provided some other party who began later has prosecuted work with superior diligence and has commenced to use before the first party was in a condition to store and use the whole of what he had claimed. Hence certain reservoirs in this district have a right to fill to a certain height and then fill to their full capacity after others are filled or partly filled. A record of the rights of reservoirs is gradually being had similar to that of canals, but these rights are in an inchoate state until the supreme court passes on them.

LEGISLATIVE AND JUDICIAL CONTROL OF WATER.

From the preceding statements regarding the canals and reservoir systems of Cache la Poudre Valley, the attempts made at water storage, and the complications arising, it is apparent that a considerable body of laws and court decisions must have been developed. It has been from this district, in fact, that many of the most perplexing water questions have arisen, and its public men have been foremost in the presentation and discussion of bills designed to protect irrigators *in the enjoyment* of the waters to which they are by use entitled.

ORIGIN OF THE COLORADO SYSTEM.

The canals irrigating the lands of Union Colony were among the lowest taken from Cache la Poudre Creek. In the years succeeding the founding of the colony new canals were built higher up the valley and old ones enlarged. As a consequence, in the latter part of the year 1874, a time of unusual scarcity, the river was dry at the head of the canal that supplied the town, and there was great danger that trees, small fruits, and lawns would be ruined. A meeting was called, about 40 delegates representing the various irrigation interests being present. A proposition was offered to appoint a disinterested person to divide the water according to the necessities of the users, disregarding, for the present, priority of appropriation—a doctrine which was generally recognized, but which under the conditions then existing was found impracticable.

The men upstream would not listen to compromise, relying upon their advantage of position, nor would most of the Greeley people accept it, as they were afraid that the concession would be used as a precedent, and that they would thereby lose an undoubted right. Debate ran high. Threats of appeals to arms were freely exchanged. But at last the men above agreed to let down some water to save the most valued trees and shrubs in the town. The promise was not kept, and violence would have been resorted to but for a timely heavy rain, which both raised the river and moistened the parched gardens and lawns of the town and the fields in the country. From that day forth the people of Union Colony set their hearts upon having a law enacted to enable them to have the water of the river distributed according to the vested rights of all concerned. Still for some time no one outside could be led to take an interest in legislation of this kind, and the years 1875, 1876, and 1877 passed without anything being accomplished.

The constitution of the State, adopted in 1876, recognized in express terms the right of citizens to appropriate the waters of the State for beneficial uses, domestic, agricultural, and mechanical; but there was then no law to give this provision efficacy. Soon, however, other communities, especially the settlers on St. Vrain and Boulder creeks, encountered like difficulties, and the farmers around Fort Collins, who had at first opposed legislation providing for a distribution of water according to the rights of prior appropriators, began to favor it when they saw large enterprises inaugurated for the purpose of taking the water out of the river much higher up than the head of their canals, and thus threatening to deprive them of the advantage of position they had been enjoying.

IRRIGATION CONVENTION OF 1878.

As a result of the general appreciation of the need of State regulation and control, a convention of delegates representing the various

irrigation interests met in Denver late in December, 1878, for the purpose of formulating a scheme of irrigation legislation. Only the Platte Basin, now designated Division No. 1, was represented. At that time there was scarcely any irrigation carried on in those drainage basins that now constitute the other five irrigation divisions of the State. Indeed, it was not until 1885 that there was any effort made in other parts of Colorado to have the State control and divide the water, as provided in the act of 1879.

At the convention held in Denver the sentiment in favor of and against regulation by a State law was nearly evenly divided. Those from the districts where the supply in time of scarcity was exhausted were in favor of such regulation, while those who still had plenty of water were opposed, as they feared it would impose on them a needless expense. Others, especially lawyers, held that rights could be better secured through the courts.

It was finally agreed that a committee of five draft a bill for a law providing: (1) for the division of the State into water districts corresponding with areas irrigable from certain natural streams or portions of streams; (2) for the appointment by the governor of a water commissioner for each district, whose duty it should be to divide the water in his district according to a record of priority of appropriation, to be ascertained by some sort of judicial proceeding; (3) for regulations in regard to construction and right of way for reservoirs; (4) for the appointment of a State engineer and for gaging the streams of the State.

The committee, consisting of David Boyd, of Greeley, chairman; John C. Abbot, of Fort Collins; Dr. I. L. Bond, of Boulder; Daniel Witter and J. S. Stanger, of Denver, drafted a bill, which in its essential features became law by the action of the next legislature. The provisions, however, relating to a State engineer and providing for the gaging of the streams were rejected on the ground that it would be too expensive to the State, the agricultural interests of Colorado being then deemed insignificant. It became apparent by the time the next legislature met that little could be accomplished without a State engineer empowered to make measurements of water, and provision was accordingly made therefor.

DIVISION INTO DISTRICTS.

For the benefit of those who are studying the Colorado system or endeavoring to amend or improve State or local regulations it is proper to present some of the difficulties that beset this committee, of which the writer was chairman, in its attempt to draft a bill providing for the matters above named. One of the most perplexing things to determine was how much land should be embraced in an irrigation district or area within which priority of appropriation as conferring priority of right to use should be applied, and a record made as a basis of divi-

sion by the agents appointed for that purpose. Theoretically, such a record should embrace what is contained in one of the six grand divisions into which at a later date the State was divided.

The question was narrowed down to whether the whole South Platte and its tributaries within the State should be embraced in one record and be under one administration, or should be subdivided into a number of districts, for each of which a record of appropriations should be made without reference to the claims of the other districts of the division. It was finally decided that a record of the whole South Platte basin, covering so large a territory and embracing so many claims to water, would require for preparation an excessively long period, and that it would be almost impossible to execute the decrees, even when tabulated.

Eight of the districts now shown in Division I of the drainage map were then created. The first extended from the State line to the mouth of Cache la Poudre Creek; the second, from there to the mouth of Clear Creek, near Denver, taking in only the main channel of the Platte. Cache la Poudre basin was made the third and Big Thompson basin the fourth. St. Vrain Creek, except its main tributary, Boulder Creek, became No. 5; North and South Boulder creeks, No. 6; Clear Creek, No. 7, and the Platte above Clear Creek, No. 8. This latter was divided later into three, Bear Creek becoming No. 9, and all of the Platte above the canyon in South Park was numbered 23.

Recently district No. 1, which was about 150 miles in length, was divided into two districts, the lower one being numbered 64. South of this, Nos. 65 and 49 were created, both taking water from the upper forks of the Republican, which are dry creeks for the greater part of the year. Three other districts, which take their waters from the upper tributaries of the North Platte before they cross into Wyoming, were numbered 46, 47, and 48, and added to the first division. These five districts outside of the South Platte basin are relatively insignificant from an agricultural point of view.

In carrying out this scheme of districts, each with a separate record and administrative officers, the results were favorable as regards Nos. 3, 4, 5, 6, 7, and 8, each of which had an independent permanent supply from the mountains; but they were not so in numbers 1 and 2, which were wholly dependent upon streams passing through the six districts first named. The trouble was first felt in district No. 2, in which are situated the earliest ditches of the State, and which is supplied almost wholly by the streams embraced in what originally were Nos. 7 and 8. The vicinity of these latter to the city of Denver led to great development in the way of irrigation works about the year 1880 and thereafter, and when put in operation they soon exhausted the supply which district No. 2, on the Platte below Denver, had formerly received.

SUPERINTENDENTS.

The increasing difficulties in district No. 2 led to the enactment in 1887 of a law providing for division superintendents. The more important of the duties of each of these are as follows: Within thirty days after his appointment each superintendent of irrigation shall send notice to the clerk of the district court of counties in which judicial decrees have been rendered, fixing the priorities of appropriation, and shall request of the clerk a certified copy of every decree establishing such priorities. The superintendent shall then cause to be prepared a book to be entitled "The register of priorities of appropriation of water rights for division No. —, State of Colorado," within which he shall enter certified copies of decrees, and shall make out a list of all ditches, canals, and reservoirs entitled to appropriations of water within his division, arranging and numbering these in consecutive order, according to the dates of their respective appropriations within his division, and without regard to the number which they may bear within their respective water districts.

Water commissioners of the different districts are to report from time to time to their division superintendent the state of the water supply in their respective districts. From these reports he is "to ascertain what ditches, canals, and reservoirs are and what are not receiving their proper supply of water, and if it shall appear that in any district in that division any ditch, canal, or reservoir is receiving water whose priority postdates that of the ditch, canal, or reservoir in another district, as ascertained from his register, he shall at once order such postdated ditch, canal, or reservoir shut down and the water to be given to the elder ditch, canal, or reservoir, his orders being directed at all times to the enforcement of priority of appropriation, according to his tabulated statement of priorities, to the whole division and without regard to the district within which the ditches, canals, and reservoirs may be located." The district commissioners are subject to the orders of the superintendent, who may enter their districts and enforce his own orders if they are refused or neglected.

These rules read well, but they have been found impossible of execution. The water supply became deficient about the 1st of June, 1890. Many of the older canals in district No. 2 were empty, and an attempt was made to supply them by shutting down canals in other districts that postdated them. An order was given to cut off the supply of the Farmers' High Line and of four other large canals taking water from Clear Creek. The owners of these canals got a temporary injunction, which was afterwards made permanent, restraining the superintendent from shutting them off. The reasons given by the court for granting the injunction were—

First, that the superintendent did not have the necessary information from the water commissioner, in the form prescribed by law, on *which to base* his order.

Second, that the ditches in district 23, embracing the South Park, were not ordered closed to a date corresponding to those in the valley.

Third, that the law of 1887, which creates the office of superintendent and defines his duties, is unconstitutional, in so far as its effect is to determine rights of priority in the waters of the natural streams against persons who have had no day in court, by making the decrees rendered in one district binding and conclusive against claimants in another separate and distinct district who have also received decrees.

In regard to the first reason, it may be said that the kind of information required by the law to be obtained from the water commissioner to guide the superintendent in regulating the supply among the different districts of the division is difficult to procure from so wide a territory, and comes too late to aid him execute his trust with the promptness which the exigency of the situation demands. If a canal needs and is entitled to water to-day, it is usually ruinous to wait for ten days while the superintendent is getting the legal information, and hence the superintendent has to act, if at all, on the most uncertain and usually biased evidence.

The situation in district No. 23 may be examined somewhat at length, as it brings to light some interesting irrigation situations.

The water commissioner of district No. 23, after consulting with attorneys, declined to shut down any ditches whatever. The superintendent then made a personal inspection of the district, and endeavored to obtain the necessary information as to location of ditches, to enable him to close them down himself; but in addition to being unable to secure the needed information, he found that in the excited condition of the people it would require the State militia to enforce his order.

This was the last effort made to shut off the ditches of the South Park district, so far as the writer has been able to learn. The district is very large, containing about 2,500 square miles. The number of ditches reported is 209. Over 77,000 acres are claimed as under irrigation, all being native meadow land except about 300 acres. The quantity of water decreed to this land by the court is 4,665 second-feet—sufficient, if the ditches could carry it, to flood the area irrigated a foot deep every 8.7 days. Measurements made by the State engineer discovered the fact that many of the ditches fell far short of their decreed allowance, some receiving only about one-tenth of that amount.

It was, moreover, claimed by the users of water in this district that the early and heavy use of the water on the lands adjacent to the small streams that traverse the Park was a great advantage to the supply of the South Platte below its canyon, and measurements made by the State engineer seem to confirm this view. Nor is this unreasonable. This 77,000 acres of land is filled down to the bed rock with all the water the soil will hold by streams applied up to July. The irrigation is then stopped in order to cut and cure the hay. The water

rapidly seeps out of the pervious soil, increasing the discharge of the streams during the succeeding months. Assuming that the soil and gravel to the depth of 6 feet is filled with water, this will be equal to a depth of 2 feet of water, and the 77,000 acres would have a storage capacity of 154,000 acre-feet.

That this early excessive irrigation up to about July 1 has the effect claimed is borne out by the fact that the measurements of the waters of the South Platte as they pass through its canyon show it, on the average, to be much smaller than Cache la Poudre Creek at the season of high water, and considerably larger during the fall and winter months. A belief of this kind, together with the injunctions obtained in other cases where the superintendent attempted to shut water from canals of one district for the benefit of earlier ones in another, has hindered the superintendent from interfering with this or other districts.

CONSTRUCTION AND OPERATION OF CANALS.

The object of an irrigation canal is to divert water from a natural stream and take it where it can be spread over the land. Other things being equal, the shorter a canal is in proportion to the service it renders, the more economical that service. Some canals run as far as 20 miles before they can deliver any water, while others begin to deliver within a few miles of their heads. The length of a canal depends mainly upon two things, first, whether there are canals close below that cover the upper part of the lands below the new canal; and, second, the degree of abruptness with which the land rises as it recedes from the stream. If the slope or fall of the stream is great, then a canal that has a small slope will gain in the height of its bed over that of the river as many feet per mile at the end of a certain number of miles as the difference between its slope and that of the river. This height of its bed above the bed of the river will bear it far away or near to the river in proportion to the steepness of the land lying between the canal and river.

The slope of the upper part of Cache la Poudre Creek after it leaves the canyon is for a number of miles 15 feet per mile, which gradually changes to 10 feet per mile at its mouth, giving an average of about 13 feet per mile. Assuming that a canal like the Larimer and Weld is started within a few miles of the canyon on a slope of 2 feet to the mile and follows the contour of the country to the north of the river for 65 miles, and that the meanderings of the canal and of the river are about the same, it is evident that at the lower end of the canal it should be 715 feet above the river at a point on the latter opposite to this terminus. However, where this opposite point in the river is to be taken is really determinable only by measuring down the river a distance of 65 miles, following all its meanderings.

The height of the Larimer and Weld Canal where it crosses the Denver Pacific Railroad, about 9 miles above the river, is 250 feet *above the river* crossing. The length of the canal to this point is

about 50 miles, and accordingly, estimating a gain of 11 feet to the mile, it should be 550 feet above the river. The railroad distance in the river valley from Greeley to the head of the Larimer and Weld is 26 miles, which, multiplied by the grade of the road, assumed as 13 feet, gives 338, and this reduced by the fall of the canal for 50 miles, namely, 100 feet, gives a height theoretically of 238 feet. Hence it is to be assumed that the fall given to the river is that of a comparatively straight line running up its valley, and not the real slope of its bed, which must be about only half as much, since the bed of the river is more crooked than that of the canal. In Lone Tree Valley, which terminates at the mouth of Cache la Poudre Creek, and which has a nearly uniform slope of 25 feet to the mile, the distance of the Larimer and Weld Canal from the mouth of the creek is 12 miles. This would give a height of 300 feet, which corresponds closely with the other estimates, this point in the canal being about 60 miles from its upper end.

These relative slopes must be taken into account when any irrigation enterprise is contemplated in connection with considerations as to the fall which can be allowed a canal of a given carrying capacity without wearing its bed. Other related questions come, as to the alignment of the canal, the straightening by cutting and filling, and increasing the velocity; also how far shall the earth removed in excavation be placed back from the edge of the cut in forming the embankments, whether there shall be two embankments or only one (on the lower side) where there is a fill, and where, if there is only one, the water will run far back on the opposite side.

The experience gained from the results of the construction of two canals in our valley by the same engineer is deemed of practical value on these points. Union Colony Canal No. 2 was given a grade of 3.2 feet to the mile, a depth of only 2 feet, and a width on the bottom of 12 feet at the head. The course was very crooked, keeping for the most part in the ground, neither cutting nor filling much; the earth was piled close to the edge of the lower bank, and no embankment was made on the upper side, however far back the water might flow. This was economical in construction, but wasteful in the long run. The slope was none too much for the canal at the size it was first built, but it was finally enlarged to some five times its original capacity. The sharp bends were of necessity taken out, thus shortening the course and increasing the slope. The upper side had to be embanked where the water flowed far back, in order to prevent the action of waves on the lower bank and waste by evaporation; also to allow of the canal being filled and emptied rapidly.

The result of these changes was a great increase in velocity and resulting wear of the bed, which has now to be checked wherever water is taken from it. Portions of the bed not influenced by these checks are being worn away, and hence are in a condition to permit

great loss by percolation. The lower bank has been allowed to remain where it was, but should have been set well back, because wherever there is much wear on the lower bank there is great danger of break. The expense of moving the earth back some 6 feet is insignificant compared to the advantage of having it there.

The experience gained in the construction of Cache la Poudre Canal was of value in laying out the Larimer and Weld Canal some eight years afterwards. In general the slope planned was only 2 feet to the mile except for a mile and a half near the head, where the bed of the canal was over large bowlders similar to those in the bed of the river at the same place and where the fall was 15 feet to the mile. This part was given 13 feet fall to the mile, and has stood the wear without being materially moved. The lower bank was set back some 6 feet and usually made broad enough to allow the driving of a wagon along its top. Cuts and fills were made to some extent to preserve the alignment from abrupt angles, care being taken, however, not to cut too deep when this would prevent the water from being taken onto the land near the canal. Small expansions of the canal on the upper side were prevented by an upper embankment, except at Lake Lee, described on page 39. This serves a useful purpose for storing small quantities received from the river in time of scarcity to be delivered to alternate sections of the canal in amounts that can be economically applied. Another expansion of this kind near the lower end was found to be wasteful in times of low water, and a canal has been cut around its lower margin to keep the water out of it except when there is a surplus. On the whole, this canal has too much slope for its present size, and usually must be checked where water is taken into laterals.

CONTROL BY TELEPHONE.

This district is probably unique in the possession of a special telephone line for water control. This line was erected in 1889, being in part paid for by the two counties of Larimer and Weld, and in part by the large canals. It cost $1,500 and is an annual expense of about $60. The river commissioner regards it as worth each year its entire cost to the several users of water.

Its upper terminus is at the head of the Larimer County Canal; thence it connects with La Porte, where the river commissioner lives, some 4 miles above Fort Collins. It has two connections with offices of canal companies in the latter place, one each at the head of the Larimer and Weld and Cache La Poudre canals, two in Greeley, and one in Lucerne.

At three different places, at three set times, the river commissioner can be communicated with by those having the irrigation affairs of the district in charge. At the head of each of the three principal canals a man stays day and night, and the bell of the telephone is *close to his* ear when he is in bed. If there should be a sudden rise

of water in the river and the commissioner is notified of it, he can immediately communicate with these three men at the head of these canals and have them raise their gates to save it. If a break occurs in a canal, the party who discovers it can communicate with the man at the head by going to the nearest telephone station and have the water shut out in the shortest possible time, decreasing the damage.

The river commissioner must visit the gaging station daily to see how much water is in the river, this being his guide for supplying the different claimants according to their priorities. The station has a self-registering apparatus which gives the different heights to which the water rises during the twenty-four hours, and from the height in the channel the number of feet per second is found from a table experimentally prepared by the State engineer. The section where the measurement is made has masonry sides and a natural rock bottom, which give a definitely fixed cross section. Means of gaging every canal diverting water from the river are required to be put in by the owners, and these gagings are rated by the State engineer for the benefit of the river commissioner. Some of the smaller canals neglect to do this, and their water supply is estimated by the commissioner.

LATERALS.

The water is taken out of the canals by means of lateral ditches placed at short intervals. Usually they follow the crest of the ridges, and deliver water on both sides by means of sublaterals. Some of these laterals are very large, as, for example, those from the Larimer and Weld Canal. These carry as much as 100 second-feet, and in some instances have two ditch riders to distribute the water to the consumers. The laterals run as far as possible on the crests of the ridges that divide the valleys from one another, and the conditions in regard to their location are such that they can not be given any slope desired but must conform to the fall of the ridge followed. The average slope of the land between the canals and the river is about 25 feet to the mile. Hence, in general, the lateral has a fall as great as that. This will not cut very badly under a flow of a few feet of water, but with 100 second-feet, as with two laterals of the Larimer and Weld Canal, there is nothing to do but to put in drops here and there after the cutting has gone on for some time. These are built of 2-inch plank nailed to suitable timbers. It is deemed best to have a lower horizontal section of planked bottom and to give the water a forward instead of a sloping downward direction when it resumes its course in the channel of the canal.

MEASURING AND DIVIDING WATER.

From the main lateral, if it be a large one, the users divert water one or many at a time. It is measured to them, or a proportionate part of it set off for them, wherever it is deemed best. The quantity

taken in by the lateral is estimated by the main canal ditch rider. Usually the measurement is made over a weir some distance below the head, and is computed from a table furnished by the State engineer, applying accurately, however, only to weirs put in according to the Francis plan. Large discrepancies are found in some of these weirs by accurate measurement. Usually more water is given than intended, as conditions for controlling velocity of approach are rarely present.

The Larimer and Weld Canal uses weir measurements. By its contracts it is bound to furnish 1.44 cubic feet per second for each 80-acre water right if this amount can be had from the river. In the other canals measurement is not necessary, since the consumers are at the same time owners of the canals and each has a proportionate right to all the canal can or does carry. Hence equitable division is all that is required. The usual course to effect this is to give for each water right so many sectional inches. This is fair, provided the sections

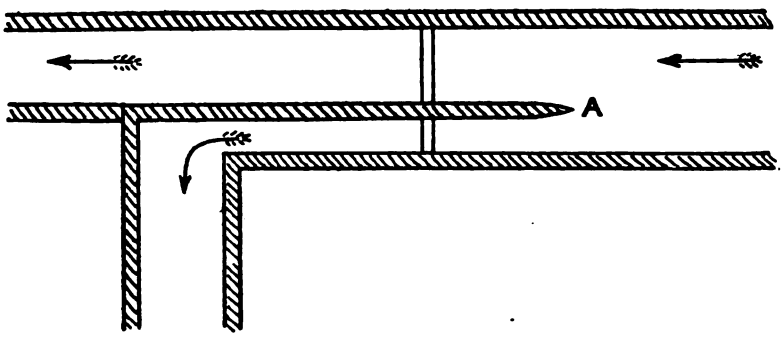


FIG. 8.—Plan of device for dividing water.

are of the same depth and the velocity of approach to the place where the section is measured is the same. The first condition can usually be secured, but often is not, and there is no uniformity in conditions to secure equal velocity of approach.

In the Cache la Poudre Canal devices called Max Clark boxes were put in both to measure and make a fair division. It was a modification of the Italian Soldati modulus, and at least did something toward making the velocity of approach to the measuring apertures uniform. It is not practicable to place a dividing device cutting off a proportionate portion of the whole in a large canal at each place where water is diverted, nor is this found practicable at the upper end of large laterals, but in the lower ends of these, and in laterals in general carrying not more than 25 second-feet, it can be done quite satisfactorily. A very simple and common form of divisor[1] is shown in fig. 8.

The partition at A is movable and may be placed at different distances from the side. When there is no desire to change the relative

[1] Measurement and division of water, L. G. Carpenter, Bulletin No. 27, Colorado Experiment Station, August, 1894, p. 9.

quantities taken through the two openings, the partition is fixed. This is usually the case, as it prevents changes being readily made by dishonest parties. When this partition is fixed, alterations can be made to suit parties by putting in a perpendicular strip of board in one side or the other. The view in Pl. XVII shows a device in laterals of Greeley Canal No. 2 by which the stream is divided into four parts.

COST OF IRRIGATION.

It has been impossible to obtain reliable figures concerning the cost of all of the canals and ditches taking water from Cache la Poudre Creek, but, as stated on previous pages, the expenditures in the construction of the two larger canals are shown approximately. The first of these, the Cache la Poudre, as stated on page 32, cost $112,000, and its reservoir $110,000; in all, $222,000. The cost of the Larimer and Weld has been placed at $150,000 for the canal, and for the two main reservoirs, $165,000, this including the estimated cost of completing the Windsor Reservoir. The total cost of this canal and its reservoirs is thus $315,000, and for the two canal systems, $537,000.

The total area of land in crops under these two canals, not including that designated as waste and pasture land, is 66,349 acres. This number of acres divided into the cost as just given gives an average of less than $9 per acre for the water. The price originally paid the railroad company for the land was $3 per acre, making a total first cost of land and water of $12 per acre. Until about 1895 this land, with water rights, has been considered as worth on an average $40 per acre without buildings. As a rule, the lands have actually been held at a higher figure than this.

Omitting the other two large canals on the north side of the river, viz, the Larimer County and North Poudre canals, a comparison of the cost and value of the remaining irrigating ditches would compare favorably with these figures, except in the case where the lands under some of the ditches have been injured by excessive seepage and by the rise of alkali. If, however, these two large canals are considered, a different estimate must be made. Both of these were built after the supply in the river was practically exhausted and when extraordinary expenditures had to be made to secure a supply.

The Larimer County canals on the plains cost about $90,000, the part in the mountains approximately the same, $90,000, and the two main reservoirs $24,000. Estimating the cost of the other reservoir at $10,000, the total is $214,000. With this expenditure, only 16,713 acres were reported in crops, making a cost per acre for water of about $13, or 40 per cent more than in the cases above cited. Besides this larger cost, the land under the canal, on account of uncertainty of supply, has a relatively small value, dependent largely upon the success of the Sky Line Canal. If this and the reservoir system

result according to the anticipation of their projectors, the lands will be as valuable as those under other canals. The unfortunate condition of the North Poudre Canal has been mentioned on a preceding page, its financial success being dependent largely upon the possibility of diverting some of the headwaters of Grand River into Cache la Poudre Valley, in a manner similar to that of the Sky Line Ditch.

As to the cost of maintenance, it may be stated that the three principal canals of the valley employed each three riders, and there is also one man at the head and a general superintendent. The cost for supervision for the years 1893 and 1894, as reported by the river commissioner for this district, was $17,502, and the cost of repairs for all canals having superintendents was $52,472. It is assumed that these figures relate only to the expenses of the canals and not to the laterals. Taking the length of the former at 333 miles and the area in crop as 125,000 acres, the cost for superintendence and repairs per annum would be 28 cents per acre.

AGRICULTURAL PRACTICE.

Whenever sufficient water is obtained and applied at the right times, the products of the lands within this valley are remarkable. Fertility is, however, maintained largely by a judicious rotation of crops. The best practice is that in which about one-third the area is kept in alfalfa, to be plowed under after two years' use as a meadow. Both the upper and lower ends of the valley are excellent for small grains and alfalfa, but the lower part is best for potatoes, and the upper for apple orchards, of which a great acreage has been planted within a few years. The more clayey soil of the upper end of the valley renders it more retentive of moisture during the winter and early spring, and hence the trees do not suffer so much from dry winds and occasional hot suns as they do on more porous soils. Blight has been severe on all the fruit trees of the valley save plums, which do well everywhere in the State.

The farms of the Greeley colony under Canal No. 2, now known as Cache la Poudre Canal, are rarely smaller than 80 acres or larger than 160. The latter is regarded as the better size for profitable farming if the owner does not get too heavily into debt. The interest at 8 per cent and the yearly payment of installments on a large farm are a heavy load even for this fertile valley, and are a fixed sum, while the profits are uncertain. The operating of the larger farms is more profitable from the fact that as much farm machinery is needed for the 80 acres as for the larger tract. If the farmer is raising grain, alfalfa, and potatoes, he needs three distinct lines of machinery. A good equipment of these and all kinds of implements needed to turn and stir the soil and move the crops will cost not less than $800. There is a much smaller proportionate investment for the larger than for the *smaller farms.*

VIEW OF DIVISION FLUME IN LATERAL UNDER THE GREELEY NO 2 CANAL.

The size of the farm which may be made the more profitable depends upon the man. If the owner is a good worker himself, but unskilled in handling men and in management, then the smaller farm will be best. Many men on an 80-acre farm have done well, made a good living, put up good farm buildings, and have money out on interest. Others have done equally well with 160-acre farms, one-half of which they went in debt for, while others undertaking this have lost all.

APPLYING WATER.

The farmer having his share of the water in his own little ditch carries it to the highest point on his farm and leads it either along the side, end, or obliquely across in straight or curved lines, so as to keep it where it can fill the smaller ditches. By these the water is carried, if possible, to every square yard of the farm. Often much diking must be done on the farm, and before the lateral reaches it, so as to get the main distributing ditch where it will cover the most land. These dikes are expensive to make and equally so to keep up, and are a source of perpetual annoyance and often of waste. A farm is to be preferred whose feeding lateral runs along one side and does not meander here and there. A farm with a sag anywhere in it, especially in the middle, is to be avoided.

The ideal surface for irrigation is one raised a little at one end or on one side. It should have a fall of from 15 to 25 feet to the mile, as uniform as possible, and in one direction. For an 80-acre tract the following conditions, if they could be realized, would be best: The upper shorter side should have a fall of about 5 feet to the mile for the feeding-head lateral, and the long direction a fall of 15 feet to the mile, with the lower short end having the same fall as the upper. It will be seen that the upper ditch, which is a quarter of a mile long, will have but a fall of 1¼ feet, and a dam put into it at intervals of 10 rods will make a difference of level of such a section of only 2 inches. If fifty rows of potatoes head into such a ditch and there is a sufficient volume of water in it to furnish a little stream for every row, it can easily be diverted into all at a time, since the diminished head will make up for the fall of level of the lower end of the bottom of the ditch, while, if the fall in this feeder was great, only a few of the rows close to the dam could be fed, and those unequally, without constant care and changing. This is the ideal surface slope for a potato field. Such tracts may be found north of Greeley and extending up to Eaton.

Such a surface is also desirable for grain or alfalfa, and to irrigate these crops by flooding, as is customary, the farmer has only to run through the grainfield or meadow a large double-moldboard plow, drawn by from four to six heavy horses, and penetrating to a depth of 12 inches, throwing a bank to each side and leaving a clean ditch behind it. These ditches are usually put a hundred feet apart, and

plowed in before harvesting, but in an alfalfa field they are left permanently. At suitable intervals a canvas dam is put into the ditch, the pole to which the edge of the canvas is nailed supported on both banks. The cloth lies in the bottom and on the edges of the ditch and is kept down by a little dirt put on the edge. The bank is cut on one or both sides as desired, just above the dam.

The use of the canvas dam is illustrated in Pls. XVIII and XIX. The former view shows a man with a canvas dam in his hand ready to put it in the lateral flowing through a field of young alfalfa. This view was taken on September 20, 1896, of a field under the Larimer and Weld Canal, near the town of Lucerne. On the left and in the distance are shown stacks of wheat recently cropped from the field. Pl. XIX shows the canvas dam in place turning out water for the irrigation of a wheat field near Greeley. The stream, checked in its flow, is forced to find its way into the young grain.

Little has been done in Cache la Poudre Valley in the way of leveling the land preparatory to irrigation. This is necessary only with rolling land, and especially where there is but little fall to it. Even when the surface is quite uneven, if there is considerable fall, a farmer can generally lead the water over the higher spots, while when it is nearly level it can be got onto these spots only by diking the ditches that run through the field. These dikes within a field are a nuisance, and in most cases it is better to level down the humps. For this sort of work various kinds of scrapers are used.

If a field is level to start with, it is important to keep it so and not create artificial irregularities by cultivation. This is done if the plowing is in narrow "lands," the "back" and "dead" furrows proving a great annoyance when flooding. To avoid these the farm should be divided into a suitable number of rectangular fields and each of these plowed out one year and in the next. The small rise or hollow where the corners occur will prove a slight annoyance, but the work of alternate years keeps the change of level within narrow limits. To not only keep the surface of his farm in good shape but to improve it is the care of every intelligent farmer managing an irrigated farm. The action of both plow and cultivator, if carefully directed, is to improve the level of the surface, and the irrigation of rowed crops contributes to the same effect. The loose material in the steeper parts of the rows is carried into slight depressions and left there, and in a few years these disappear. The perfect potato field is without such depressions, but a surface entirely free from them is rarely found. They are less objectionable in a cornfield, as a little flooding does it less harm than potatoes, and hence it is advisable to raise a few crops of corn at first in such fields, even if the crop is not profitable.

To raise a good crop of potatoes on a steep field requires great pains and ingenuity. If the surface is not wavy as well as steep, the rows

IRRIGATING A YOUNG ALFALFA FIELD.

can be run diagonally across the slope, so as not to give them too much fall, which will make the bottoms wash away and lower the water surface, so that the rows are not moistened underneath. Some farmers run the rows directly down a steep slope, and in irrigating let a tiny stream trickle down between the rows for a day or two, and thus succeed in having the moisture penetrate the rows. To get the water to enter so many rows at once requires a very level head-feeding ditch, or the greatest pains and ingenuity in the way of checks to effect that end.

In general it may be said that steep, rolling, irregular land is much less desirable in a country that is irrigated than in one where it rains, and such a farm should be avoided, however rich the soil may naturally be. Still, if the soil is a pretty stiff clay, it may be irrigated without tearing it to pieces, even if rather steep; but in this case it is next to impossible to spread the water so evenly and thinly that the soil can absorb all that is applied, and hence usually a large portion of that used runs off into hollows and draws and is lost to the owner.

ALFALFA.

Alfalfa can be raised at a profit for $3 per ton in the stack in the field. The average weight of the crop is variously computed by those who make careful estimates at from 3 to 4 tons per acre for the three crops, and it costs from $1 to $1.25 per ton to put up the hay at the present reduced price of hands and haying implements. At these figures an income of $5 per acre can be safely estimated from land put down to alfalfa. Seed costing $1.50 will sow an acre. It is now usually seeded with the spring-sown grain, and if one does not want to plow it under for fertilizing purposes, a stand will last twelve years or more.

These figures differ widely from those given in Arizona and the Pecos Valley, New Mexico, where crops of 8 tons per annum and prices of $10 per ton are claimed. From personal observation the alfalfa fields near Phœnix, Arizona, do not show such luxuriance as those of Cache la Poudre Valley. In considering the price of alfalfa hay the true test is what it is worth to feed on the farm, and not its temporary local price when a country is being opened up. Such is the productiveness of this plant that if any considerable area is brought into cultivation the local market is soon glutted. Thus the only safe basis of price is its feeding value and the probable permanent selling price of the meat produced from feeding it.

By adhering principally to alfalfa raising and stock feeding, it will be seen, a fair rental can be expected from land, and $40 per acre would be a conservative price for such land. Large tracts of land can be handled economically by one management if alfalfa alone is made the crop, and hence men who possess farms of considerable size are drifting into this crop and find it more profitable in the long run than renting in small tracts for mixed husbandry. This latter practice is

sure to run down a farm in a few years, while alfalfa farming at once keeps the land clean and increases its fertility amazingly. The best and most profitable farming here is done by men who own a moderately large farm and practice a mixed husbandry.

POTATOES.

Potatoes are usually planted after plowing under alfalfa. Two crops can then be successfully produced. Some farmers raise the two crops in succession, while others raise a wheat crop between. The former is the better way, as the land is usually too rich for the wheat if only one potato crop is raised. Besides, it often happens that the raising of one potato crop does not entirely kill the alfalfa, in which case it comes up in the wheat next year and smothers it, making it difficult to harvest. Usually the second crop of potatoes is the better, as there is likely to be a larger stand than when so much growth of roots and stubble are turned under and partly mixed with the soil, since the latter dries out rapidly from the free circulation of the air admitted by this light material.

The breaking of a well-set alfalfa field is no trifling matter. It may be done with three heavy horses, but it is hard work for them, and they will not be able to break more than 1 acre a day. The writer prefers using five heavy horses—three in the lead and two on the end of the beam. They can go right along and plow 2 acres a day. Alfalfa roots are very large and strong when the plants have attained a full growth. They give a jerky motion to the plow and it makes hard work for horses' shoulders. A cast-steel plow is used, and the share is so tempered that a file can just cut it. It is hammered out thin at the blacksmith's shop when it gets too thick to file easily. The reason for filing, rather than using the hard, thin edge, as in other plowing, is that the edge needs to be rough as well as thin, or the roots will slip along the sloping edge of the share and not cut well. In breaking, the plowing is done from 6 to 8 inches deep. In plowing stubble the practice is to get down about 10 inches.

If water can be had, it is better to irrigate the alfalfa field before plowing. It will be dry enough to plant in three days if it has not rained meantime. It is usual to harrow down or run over with a packer and leveler daily, so as to retain the moisture as much as possible.

The planting is now done with an Aspinwall planter, which may be regulated to plant from 11 to 23 inches apart. Good seed is indispensable, and is often hard to get. Under our forced cultivation the tubers deteriorate rapidly in form and vitality. Often the sprouts, when they start in the spring, are no thicker than knitting needles. A thin, weakly stand is sure to follow from the use of such seed. Seed is shipped in from sections where they are grown by natural *rainfall*. In 1896 a carload was obtained from the divide lying

IRRIGATING A WHEAT FIELD.

between Denver and Colorado Springs, a high region where the rainfall exceeds that of the plains, and where it suffices in spots here and there to produce a moderate-sized crop without irrigation. A new supply of seed seems to be needed about every three years to keep the stock in good shape, but much can be done by careful selection of home-grown seed. Storage in a comparatively damp cellar or dugout is now believed to keep up the vitality of the tubers better than storage in a very dry cellar. The latter tends to induce dry rot by the time the planting is being done, which is from May 15 to about June 10.

Early planted potatoes usually do not thrive well in this climate. The soil is too hot in July for the tubers, and if an attempt is made to keep down the temperature by frequent irrigation, the vines usually blight, turning yellow, both stem and leaves getting stiff. It is better to delay all irrigation until about the first of August, when the vines are beginning to blossom and the small tubers are beginning to form. August is much cooler here than July, the nights are longer, and there is more light rainfall and cloudy weather, all of which are aids to irrigation.

Soon after planting and before the potatoes come through, they are cultivated as deep as the ground is plowed with a two-horse cultivator, the soil being thrown onto the rows. The cultivator is followed by a fine-toothed harrow, nearly leveling its work but destroying all weeds and leaving the ground mellow. Two more cultivations are given, the last one throwing up the earth around the plants. This cultivation is followed by running through either a large single shovel with wings or a lister which makes a clean continuous ditch, but not quite down to the depth of the plowing. The top of the ridge is from 10 to 12 inches above the bottoms of the furrows.

By about August the vines have made a fair growth from the moisture stored in the soil and the light rainfalls. The roots have spread beneath the surface in the soil moved by the plow, and many of them have penetrated the unmoved soil in search of water. This is a healthy and thrifty movement on their part, and they are in a good position to utilize the moisture furnished them by irrigation. Water is allowed to flow gently between the rows, a larger stream being allowed to enter the rows when the land is level, so as to force it through, but if steep, it must be allowed to flow long and slowly on account of washing, and the irrigations must be repeated oftener. On level land two irrigations are usually sufficient, while four are none too many where the ground is steep or where it is very porous.

No rules can be given about the frequency of applying water except the general one that the soil in the rows should not be allowed to dry through and through so as to arrest the growth of the tubers. If this happens, then they take a new start when water is again applied and throw out knobs and become abnormal in form.

The main crop is harvested from October 1 to October 25. Some medium early ones are taken up all through September, but these are usually too unripe to keep long. The Dawden Digger is mostly used (see Pl. XX). It requires a man and four heavy horses to run it, and if kept going ten hours can dig 5 acres. The picking is paid for by the sack, which holds about 115 pounds. The price now is about 5 cents, which includes sorting and sewing. A sorter is mostly used, a horse dragging one along for four pickers, with one man to shake it, set off full sacks, and put on empty ones. These will keep a man sewing. If the potatoes are good, these six men will pick, sew, and sort 250 sacks per day. These on an average can be had from 2½ acres if the crop is after alfalfa, but no such average is obtained from all the acres planted, even in the best potato district. The most experienced and careful men sometimes fail to get even a thrifty stand, and as much poor land, or steep and uneven land, is planted, the general average from all planted in the valley will not exceed 60 sacks to the acre.

It takes about two men and a team to haul in and store the 250 sacks, which are put away in the dugouts on the farms, the sacks being laid on their sides and piled up about eight deep. Many sacks, however, are disposed of at the various railroad stations, being either sold and shipped away or stored at the potato warehouses.

Pl. XXI is a view of the potato dugout of Mr. H. B. Eaton, in the town of Eaton. It is excavated about 3 feet deep, and earth put on top and at sides. Teams drive in and out on a gentle incline. Capacity, about 20,000 sacks of 2 bushels each.

To operate such a digging outfit requires 7 horses and 9 men. Calling the services of 7 horses equal to 3 men, we have an average of 25 sacks per man, or nearly 50 bushels dug, sorted, sacked, sewed, and put away in the dugouts.

Sometimes the potatoes are taken up unsorted and stored away in bulk in the dugouts. In this case, about a bushel is put in a sack, which is neither tied nor sewed but piled onto the wagons and then dumped into shoots from the outside. The sorting is then done in the winter and spring. The sacks cost about 4½ cents by the thousand.

For the last five or six years the price of potatoes has not exceeded 75 cents per hundred pounds, while in 1896 it was only 25 cents. They are now worth from 50 to 60 cents. The crop in 1896 was short, not much more than half that of 1894, because of very dry, hot weather in the early part of the season preventing a good, thrifty stand and vigorous growth before irrigation was commenced.

In general it may be said that the crop can be raised at a profit in an average year for 50 cents per hundred, sacked and delivered at the depot. The outfit of tools, including alfalfa breaking-plow, harrow, cultivator, planter, digger, and sorter, costs about $300. The digger is a short-lived machine, and needs, on about an average, $10 per *annum* for repairs.

VIEW IN A POTATO FIELD NEAR GREELEY.

In several years after the colony settled here there was a home market, and hence a high price, as the competition was between those raised here and those shipped in. But gradually the supply began to more than meet the home demand, and shipments had to be made into the towns on the Missouri River and into Texas. Here we came into competition with potatoes raised in Iowa, Minnesota, Wisconsin, Arizona, and sometimes Utah and California. Still, compared with those localities that do not irrigate, with which we come in competition, we have the advantage in a dry and hence scarce year, when the price is high. The size is larger and the quality usually better, and therefore we get a higher price in the same market, say by from 10 to 20 per cent. Hence we are likely to keep on raising large quantities of potatoes in this region and at fairly remunerative prices on the average. But the days for making large profits have gone.

UNDERGROUND WATERS.

The percolating waters of the valley are of considerable importance, although relatively small in quantity compared to the amount flowing on the surface. The matter of seepage water has been fully discussed by Prof. L. G. Carpenter.[1] There are, however, a number of matters in connection with the character of water and the means of bringing it to the surface that are of importance not only in this valley, but elsewhere.

ALKALINITY OF SEEPAGE WATERS.

Seepage waters are nearly always heavily impregnated with alkaline salts, and storage increases the percentage of these deleterious constituents. If a reservoir is only 15 feet deep, there would be during the summer over one-third evaporated. As the salts held in solution do not escape, the water in the reservoir will be far more saline than it was when received. If the water stored comes from the river near its head and has been but little mixed with the return seepage always impregnated with salts or alkali, its storage will not materially injure it for irrigation.

The effect on soil using alkali water exclusively is soon made visible by efflorescence on the surface. Hence it is prudent to use stored water alternately with that brought direct from the river by the canals. Then when the drainage is good it may be expected that sufficient quantities of these soluble mineral constituents will pass off, leaving the soil comparatively free. The lower, older canals are making on this ground objection to exchanging the river water for the reservoir water in the manner described on page 60. This is a serious question; for alkali is easily developed and with difficulty removed. There is practically no way of removing it but by procuring good drainage and applying plenty of fresh water to the surface,

[1] Colorado Agricultural Experiment Station Bulletin, No. 33, Seepage and Return Waters from Irrigation, by L. G. Carpenter, January, 1896.

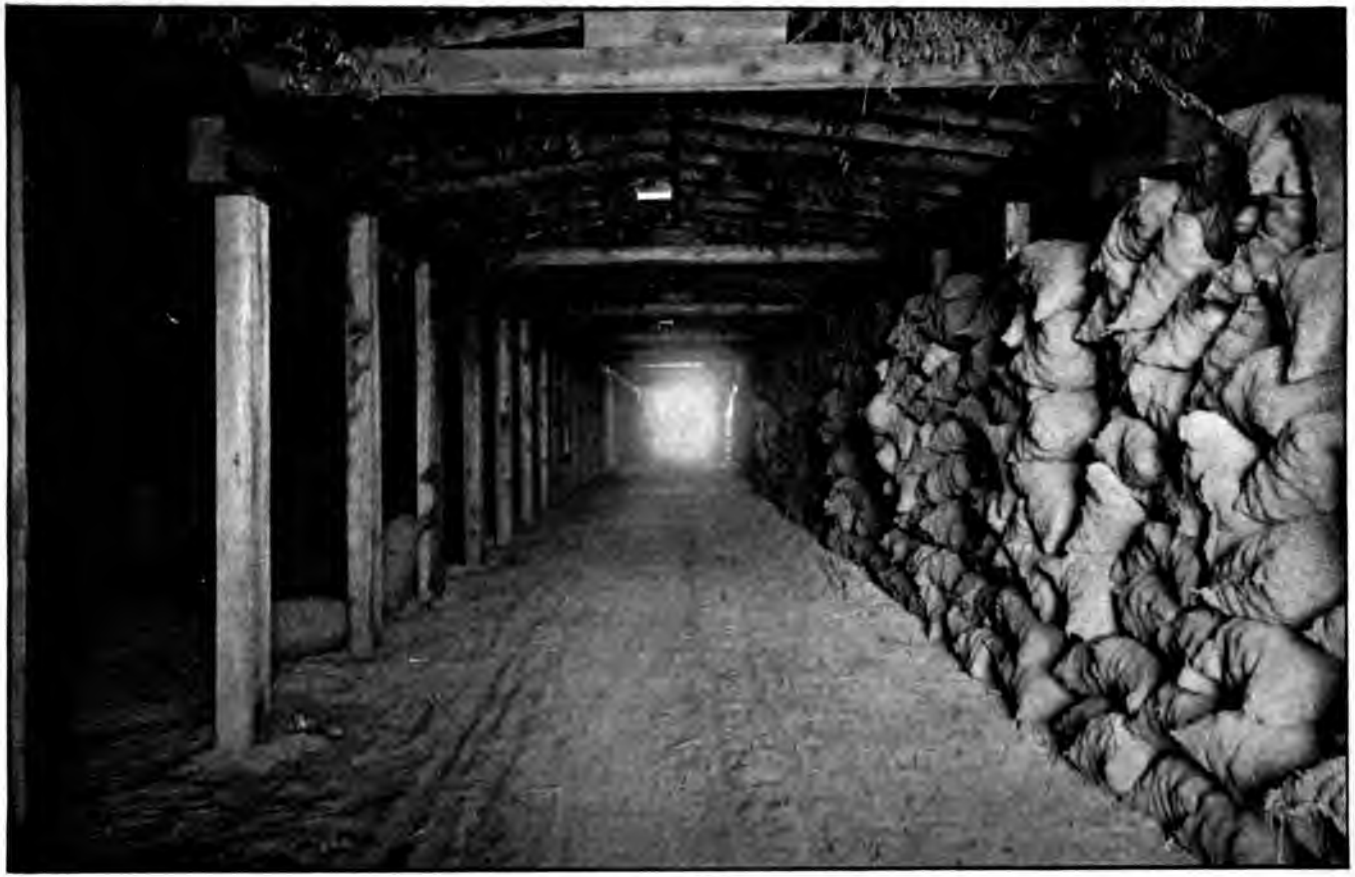
in this way dissolving and carrying off a share of it through the underdrainage. Surface flooding with fresh water will also help, but there must be good drainage, natural or artificial, or the land will be rendered too wet to raise a crop.

Little success has been made in reclaiming the wet alkali land in Cache la Poudre Valley, the most notable attempt being at the Agricultural College near Fort Collins. Here a swamp, made so by seepage water, has been deeply underdrained with tile, and the land now bears good crops. The writer undertook some work of this kind, which proved a failure because the tile were not laid deep enough to reach the sand or gravel, the chief outlet for the water that percolated through the soil. This is about 7 feet from the surface, and to tile land at that depth would cost more than the land is worth.

The drainage of the town sites of both Greeley and Fort Collins is of interest in this connection. When these towns were settled, there was no trouble in getting a dry cellar. After irrigation had been going on some three or four years, water commenced to rise in the cellars. In some of the lower places it showed itself even on the surface. Both towns are underlain with a deep gravel stratum, which it was believed would give a perfect drainage. The quantity of water applied in irrigating lawns especially, and by the great number of small ditches running nine months of the year, was more than the gravel could carry away, and so it began to force itself to the surface where lowest.

The town of Greeley first laid a deep drain on one side of Main street, extending to the river on the east and to the city limits on the west. It was put down 3 or 4 feet into the gravel. Sewer tile 18 inches in diameter was used without cementing the joints. This soon reduced the water level in the soil. There was a row of large trees along the side of the street whose rootlets penetrated the joints of the pipe and nearly filled it. This was all taken up and a larger pipe (at the lower end 2 feet) put in and the joints cemented, except at intervals of 200 feet, where manholes were left to let the water in and at which place the roots could be removed as occasion required. One cross drain was also put in, and now the drainage is satisfactory.

In the district immediately west of Greeley, and between its western boundary and Canal No. 3, water began to rise in the cellars, and about September 1, 1895, appeared on the surface a short distance west of the end of the town tile drain above described. The cause of this was traced to the removal from the bottom of the canal the winter before of the accumulated sand for the purpose of making mortar. When the water was let into the canal the spring following this removal, it was ascertained that several hours were required for the moderate volume to pass this disturbed area. The bottom of the canal is here a quite coarse gravel, allowing water to go through it like a *sieve*. The water could not be carried off by the drainage of the land



VIEW IN A POTATO DUGOUT.

below as fast as it went in. Prof. L. G. Carpenter[1] of the Agricultural College, states that a measurement of the amount of water in the ditch was made October 16, 1895. The quantity in the canal decreased from 25.86 second-feet above the place where the sand was removed to 20.80 second-feet a little distance below, or a loss of 5.06 second-feet. The total distance between the two measurements was about 760 feet. The total area of surface was about one-half acre. This would be equivalent to the discharge into the area wetted by the canal of the quantity covering it to a depth of 21 feet in twenty-four hours.

After the water was turned out of the canal, the cellars became dry, remaining so during 1896. Two years after the canal was originally constructed the same rise of the water in the soil was observed, but it disappeared after the sediment had coated over the surface of the gravel. The same effects of excessive percolation have been observed below canals of this district where the slope is so steep that the bottom is kept swept by erosion. When a check is put in, causing sediment to gather behind it, the percolation lessens or altogether disappears.

The drainage water of the city of Greeley is mingled with a limited quantity of sewage, which enters at the lower end of the discharge drain. This is carried across Cache la Poudre Creek in a wooden flume and is used for the irrigation of a market garden of about 200 acres. The quantity is approximately 5 second-feet up to about the end of the irrigation season, when it is more abundant. This drain affords an indication of the periodical fluctuation of underflow due to a change from ample irrigation to cessation. The strip irrigated is narrow, the canal not being more than from 1 to 1½ miles from the river, and the gravel bed deep and of coarse material.

PUMPING UNDERGROUND WATERS.

Nearly all of the water found in the soil and gravels comes from the percolation following irrigation. This is proved by the fact that the early wells dug in the valley often penetrated gravels without finding any water until the rock was entered. For instance, on the farm of the writer, in 1880, when the Larimer and Weld Canal was being built, a well was put down through 25 feet of soil, 25 feet of gravel, and 25 feet of shale rock. Here a thin layer of sandstone was found, yielding a small supply of hard, alkaline water. This well was about 6 miles north of Greeley, and its bottom was above that of the river, due south of it. Along the river bottom, which averages about 1¼ miles wide, water is found about on a level with that in the river, the sand and gravel underlying the soil admitting of its easy passage to and from the bed of the stream. The dip of the rock strata is toward the stream and slightly to the east.

The water in this well did not rise, indicating that there was no

[1] Seepage or Return Waters from Irrigation. L. G. Carpenter, Bull. 38, Colorado Agricultural Experiment Station, January, 1896, pp. 49 and 50.

pressure, or that the rock overlying this water-bearing sandstone was not impervious or water-tight, which was perhaps also indicated by the alkaline constitution of the water. After irrigation had been going on for two years, the water began to rise in the well, filling it up to the top of the rock and then gradually rising through the 25 feet of gravel. In five years from the digging of the well, the water stood within 25 feet of the surface, where it remains with but scarcely perceptible fluctuation. This is an example of what took place everywhere on the bench land, varied by the different conditions and depths of soil, gravel, and rock.

In Lone Tree Valley water was found at the bottom of the underlying heavy gravel bed, and an abundant supply is to be had above the Larimer and Weld Canal at a depth of 17 feet. The same condition occurs on Owl Creek, a branch that comes from the northeast. At Carrs Station, still farther north, on Lone Tree Creek, the water flows out at several places, presumably forced to the surface by the bed rock. At this latter point some small ditches furnish water to irrigate a few acres. Two wells, one pumped by steam and the other by a windmill, supply water for the irrigation of small tracts of land lying above the line of the canals.

Lone Tree Creek issues from the foothills at Granite Canyon, Wyoming. From there to the point where it ends in the Platte, at the mouth of the Poudre, is 75 miles. The watershed or catchment area has an extent of 536 square miles. The water found in the wells is quite soft, indicating that its origin is near the head of the creek. As the soil overlying the gravel is heavy clay, it is probable that but little of the rainfall penetrates it to any considerable depth, and is either evaporated or runs off from the surface into the bed of the creek. The surface run-off is an intermittent flow, but keeps its channel well defined.

In striking contrast are the conditions in this valley below the point where the Larimer and Weld Canal crosses. A short distance down the water flows permanently in the bed of the creek to such an extent that three or four small canals are taken from it. This water, unlike that usually seeping, is also quite soft, probably for the reason that the layer of soil above the gravel is thin, usually about 3 feet, and hence can furnish but little alkali to the water that percolates through it. The canal above is doubtless the principal source of the added underground water, since the bottom of its excavation must be near if not at the top of the gravel.

Two extensive pumping plants belonging to Andrew Wilson are located in Lone Tree Valley. The first is about 5 miles below the crossing of the Larimer and Weld Canal and 150 feet away from the creek channel. The depth to water here was 8 feet, and the well, 12 by 12 feet wide, was put into the water 10 feet. The well is cased with 2-inch plank, and was dug by machinery operated by a steam engine. The cost of well and two pulsometer steam pumps was $1,200.

The pumps raised a flow that, passing over a weir 2 feet wide, measured 5 inches deep. From this well in one year there were irrigated 240 acres, one-half in wheat, the other in potatoes. It took about 1 ton of coal per twelve hours, which cost at the Eaton mines, 2 miles distant, $1.50 per ton. The pump was operated night and day for about thirty days each season. This plant was erected in 1888, and the pulsometer pump was replaced in 1893 by one centrifugal pump operated by an engine, each costing $400. This is an improvement on the two pulsometers.

In 1892 Mr. Wilson put in another pumping plant, much more extensive, 2 miles farther up the creek. The well was put in a bend of the creek 93 feet from its bed. It is 12 feet by 12 feet wide and 27 feet in depth. Water here was found within 3 feet of the surface. The well cost $800, and the pump, engine, and boiler $1,700 more. The boiler is 60-horsepower, engine 35-horsepower. This pump, when operated constantly, can lower the water in the well 18 feet, leaving 6 feet still in the bottom. The pump is centrifugal and can in forty-five days raise enough water to irrigate 320 acres. It requires about 2 tons of coal a day. The coal is obtained at the same price and distance as in the first case. The owner considers this much cheaper than the purchase of rights in the Larimer and Weld Canal, in which, if obtainable, the cost is $2,000 per 80-acre water right from the canal and $800 per right for reservoir water, making an investment for water for the 320 acres of $11,200, as against $2,500 for the pumping plant. The expense of operation is considerably more, but not enough to equal the interest on the difference of capital invested.

The privilege of pumping water from his own land has not been continuously enjoyed by the owner. In the summer of 1895 he was restrained from pumping at the instance of parties who are diverting water from Lone Tree Creek below his plant. His pumps were stopped by the order of the district court about the middle of the irrigation season. He had already been through the courts in connection with his lower plant, and the case had been decided in his favor in the court of appeals at the spring term of 1893. This legal controversy is of general interest to those engaged in irrigation in the arid regions.

The district court in the first case instructed the jury as a matter of law "that water which percolates through the soil, without an evident and well-known channel, is regarded as a part of the land and belongs to the owner thereof, and he may make such use of the water as he sees fit while it remains on or under his land; second, that digging wells close to a stream, so that the waters of the stream necessarily percolates into such wells, thus diminishing the water previously appropriated, is but doing indirectly what the law forbids being done directly, and will not be allowed."

The verdict was for the defendant, because the evidence did not appear to the jury to prove that the pumping lessened the flow in

Lone Tree Creek. The court of appeals sustained the verdict "because the evidence was so vague, conflicting, and indefinite." But the court criticises the first instruction to the jury cited above in this fashion:

> It is probably safe to say that it is matter of no moment whether water reaches a certain point by percolation through the soil by a subterranean channel or by a surface channel. If by any of these natural methods it reaches the point and is there appropriated in accordance with law, the appropriator has a property in it of which he can not be divested by the wrongful diversion of another, nor can there be allowed any substantial diminution. To hold otherwise would be to concede to superior owners of land the right to all the sources of supply that go to create a stream, regardless of the rights of those who previously acquired the right to the use of water from the stream below. Strictly and technically, the instruction should not have been given. There were no facts in evidence upon which it could properly be based. But in view of the fact that nearly all the evidence was directed to the question of whether the water supply was diminished by the acts of the defendants, the finding of the jury that it was not renders the instruction harmless. The other instruction (No. 2) given by the court appears to embrace and clearly state all the law of the case.

The ditch owners apparently made two claims, one for the water visibly flowing in the channel of the stream and one for a part of the water in the gravel below, which they affirmed they had forced up by means of a dam sunk in the bed of the channel at the head of their ditch. The testimony went to show that the pumping did not reduce the visible supply, and it was not proved how much the invisible supply was affected. From the nature of the situation it can be seen that no temporary shallow dam could raise and force the subterranean water into the head of the ditch, which was about 6 feet above the water table.

The valley at this place is 2 miles wide, and the depth of the underlying gravel is about 30 feet. Even if a comparatively wide dam were put into the creek down to bed rock it could not force the water table to rise except to a very limited extent and not to approach the height necessary to enter the head of the ditch. The water after being elevated a few inches behind the dam would undoubtedly move around its flanks in the surrounding gravel. In regard to this aspect of the question the court said:

> In the case of a running surface stream the question of appropriation is of easy solution; but not so in a sunken stream, particularly where the water is at an indefinite distance below the surface. Under such circumstances it becomes at once apparent that to appropriate and utilize the water an impervious dam must be constructed and carried down to an impervious base to stop and retain the subterranean water and raise it to the ditch. Whenever such adequate provision is made, any act diminishing the quantity that would naturally reach the dam and add to the supply up to the limit of appropriation, whether by diversion upon the surface, the sinking of wells, and using pumps or otherwise, would be actionable. * * * It is in evidence that the plaintiff had constructed a dam across the stream to supply his ditch, but there is nothing in regard to the character of *the dam.* * * * The efficiency of the dam to stop, retain, and apply the sunken *water should have* been shown, for if the water found and taken by defendants

by sinking wells and pumping would, in its natural course, have passed under the dam [and he might have said around it] the available supply could not have been materially diminished.

The second case involved both wells, but has more pertinence to the upper one, which is much deeper and placed in a bend of the creek where the water was near the surface. In this case it was shown that the pumping decreased the visible supply in the creek above the heads of the ditches.

On hearing the question of making permanent the temporary injunction which he had granted, Judge Jay H. Bouton, of the district court, said: [1]

This is a case of great importance to all parties interested, and has been commenced at a very critical season of the year, and that is the reason why I thought it should be determined on its merits now. To my mind there is but one question of importance in this case, and that is as to whether the defendant, by the construction of these wells in Lone Tree Creek or its valley and the pumping of water therefrom, has diminished the flow in Lone Tree Creek so as to deprive plaintiffs of water to which they were justly entitled under their decrees as entered in this district; and perhaps preliminary to that is the question as to whether it is a well-defined stream, the water therein flowing in a clearly marked channel, either regularly or intermittently, from which the plaintiffs were entitled to their decrees of priorities. I am clearly satisfied from the evidence that both of these propositions must be answered in the affirmative. The testimony introduced on behalf of the defendant, standing alone, sufficiently establishes the fact that there was a considerable diminution in the volume of water running in Lone Tree Creek after the defendant's pumps were operated, produced evidently by sinking and pumping of water to irrigate his land. If that is true, then he has no more right to sink these wells below the level of the ground, or below the surface of the stream, and thus pump from the stream than he would have to take it directly from the bank [bed] of the stream for the same purpose by means of the construction of ditches. Of this proposition I have no doubt whatever. The motion to dissolve the injunction heretofore granted is denied.

It has been held by the court that if, as the result of pumping on one's own land, it can be proved that a surface stream is diminished to the detriment of one who has a prior right to the use of the water, it will not be allowed, no matter how the stream is fed—that is, whether it derives its water in part from percolation from the estate of the one employing the pumping plant or not. This reverses the doctrine that water mingled in the soil below the surface is part of the estate—the fluid substance being as much a part of the soil as the solid portion. In this case the true derivation of the water is not hard to trace. It is due both to the water flowing at the bottom of the gravel which underlies the valley and to the percolation from the Larimer and Weld Canal and the lands irrigated therefrom, and not to rainfall on the lands of the immediate vicinity. In consequence of this ruling there must be a great loss to this valley of water for irrigation. The quantity secured by ditches is insignificant compared with what could be pumped. The bed of the creek is nearly on a level with the top of the gravel bed, and hence can receive into its channel but a

[1] Third Colorado Court of Appeals, 430, and 33 Pacific Reports, 280.

very small portion of the underground water that is slowly moving along to ultimately make its appearance in the bed of Platte River.

Beginning in 1888 there was considerable activity in erecting pumping plants. A building was put up to manufacture what were known as the Huffer pump and the Nye pump. These, after trial, have been cast aside for the reason that the pumps did little work for the fuel consumed. They were simple in construction, and hence cheap, but they were of primitive design, dating back to the infancy of the application of steam to mechanical purposes. The Swan hot-air pump, devised by one of the men prominent in promoting pumping and the manufacture of the pumps above referred to, is perhaps as economical as any in the market. One of these has been erected on the banks of Cache la Poudre Creek, near Greeley, pumping out of the river for the irrigation of adjacent lands of H. E. Churchill. This was asserted to have a capacity of 1,000 gallons a minute, or about 2½ second-feet. The boiler was so constructed that it could burn coal slack, which cost about $2 a ton laid down, about a ton a day being required. Under usual conditions it probably lifted steadily 1½ cubic feet per second to a height of 15 feet. It was used three years, but was discontinued in 1896, the reason being given that the land cultivated was of poor quality and did not pay expenses, the price of produce being so low. Another of these pumps, raising water 30 feet, was used by J. D. Miller on his farm in connection with canal water when the latter was scarce.

ARTESIAN WATER.

As the lowest part of the valley—that at Greeley—is in the Fox Hills formation, there is little hope of striking the Dakota at moderate depths if the Cretaceous formation here is as thick as reported. R. C. Hills gives the average thickness of the beds lying between the Laramie and the Dakota at 3,500 feet. The latter sandstone outcrops behind the hogbacks near Fort Collins.

In spite of discouragements a project was started in 1883 to put down an artesian well in Greeley. Swan Bros. took a contract for drilling 800 feet. Blue shale was struck at 40 feet. No water was found at 800 feet that would overflow, and the work was prosecuted to 1,150 feet, when a fine bluish-gray sandstone was struck. The flow was quite weak, and it was decided to go farther to see if a better flow could be obtained. A depth of 2,300 feet was reached and no other flowing water was found.

Six others have been put down to this 1,150-foot water, all of which gave a weak flow until pumping was commenced in one, when the water ceased to flow in all the others. The water rises to within 40 feet of the surface. The cost of these wells to the depth of 1,150 feet is about $2,500. The water is distributed by pipes to the different parties that have put down the wells, and is highly valued for wash*ing purposes.* It is not hard, but contains matter distasteful to most

people. It was once regarded as medicinal in its properties, but now seems to have lost this reputation. The stratum of sandstone from which the water comes is about 25 feet in thickness, and on account of its fineness and hardness yields but a small flow.

Both in Greeley and in the country around it wells have lately been sunk into rocks believed to be of the Fox Hills formation. Soft water has been obtained, which, however, in no case rises to the surface. In Greeley the rock furnishing this water is struck at from 75 to 90 feet, and the water rises to within some 40 feet of the surface.

About 8 miles north of Greeley and 1 mile north of the town of Eaton an experimental well was put down by B. H. Eaton. The following account was obtained from the contractor, Dr. Swan: Above bed rock were 85 feet of soil and gravel. At 250 feet open, porous sand rock was found 30 feet thick, and in it a great abundance of soft water which rose to within 28 feet of the surface. At 450 feet a similar formation was found and the water rose to the same level. After this were shales and sandstones to 625 feet, but no overflow. At 625 feet blue limestone, 6 feet thick, was struck. The work was continued to 970 feet, but with no more sandstone nor water.

On the farm of the writer, about 3 miles south of the above, a well was put down in 1894 to a depth of 265 feet. Of this 55 feet were in soil and gravel to bed rock, the gravel being full of water to the top. Next below was a thin shale with coal indications; then a deep layer of sandstone, 80 feet thick, with plenty of hard water; then 40 feet of shale, underlain by 30 feet of sandstone, containing water, also hard; then 20 feet more of shale, when the sandstone was struck, which now yields the supply pumped from the well. The sand rock is very hard and close grained, and yields a small supply. The water comes to within 70 feet of the surface, but settles rapidly when pumped. There is 170 feet of 6-inch iron piping in the well. The total cost, pump and all, was about $500. Half a mile southeast of this well another was put down in which an abundance of soft water was found at the depth of 190 feet.

About twenty wells have been put down around the above two named within a radius of 3 miles. They vary so much in depth and in quality of water in the different sands as to lead to the inference that this country is much broken by faults and that at places the seepage water from the surface gets into the sandstone. In all the cases so far fairly soft and good drinking water is found in some of the sandstone strata and at a moderate depth, but the pressure in no instance is sufficient to make the water overflow, although it rises to varying depths from the surface.

These wells cost from $200 to $500 each, but furnish the best of drinking water, and have much improved the health of the localities where they are situated, especially in immunity from typhoid fever, the most fatal disease of this region. None of these deep wells have been put down more than 2 miles west of a line joining Eaton and Greeley.

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1895.

Sixteenth Annual Report of the United States Geological Survey, 1894-95, Part II, Papers of an economic character, 1895, octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894, octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar year 1893-94, by F. H. Newell, 1895, octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895-96, Part II, Economic geology and hydrography, 1896, octavo, 864 pp.

Contains papers by G. K. Gilbert on the underground water of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois; and by N. H. Darton on a reconnoissance of the artesian areas of a portion of the Dakotas.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896-97, Part IV, Hydrography, 1897, octavo, -- pp. (In preparation.)

Contains a progress report of stream measurements for the year 1896, by Arthur P. Davis, and four other papers relating to hydrography. The first of these is by Frank Leverett, and relates to the water resources of Ohio and Indiana, especially as obtained by wells; the next is by N. H. Darton, on the artesian waters of South Dakota, being supplementary to his paper in the Seventeenth Annual; following this is a fully illustrated paper, by James D. Schuyler, on water storage, mainly for irrigation and the construction of dams; the last paper, by Robert T. Hill, describes the artesian conditions of a portion of Texas in the vicinity of San Antonio.

Water Supply and Irrigation Papers.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

Survey bulletins can be obtained only by prepayment of cost as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier.
8. Windmills for irrigation, by E. C. Murphy.
9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker.
11. River heights for 1896, by Arthur P. Davis.

In preparation:

12. Water resources of southeastern Nebraska, by Nelson Horatio Darton

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896. Stat. L., vol. 29, p. 453.)

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